RAILROAD LOCATION SURVEYS AND ESTIMATES

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CHICAGO AND NEW YORK
THE MYRON C. CLARK PUBLISHING CO.
1908

PREFACE.

The author wishes to acknowledge his indebtedness primarily to Mr. F. A. Molitor, M. Am. Soc. C. E., formerly Chief Engineer of the Choctaw, Oklahoma & Gulf R. R. and of the Midland Valley R. R., and Mr. E. J. Beard, M. Am. Soc. C. E., formerly Principal Assistant Engineer of the C., O. & G. R. R. and of the Rock Island System, under whose direction the methods advocated herein were worked out and brought up to the high state of efficiency which made the "Choctaw" a success. There is nothing absolutely new about any of them, but either through fancied lack of time or money on the part of those responsible, or because they have lacked the courage of their convictions, few railroad location surveys, in this country at least, have been so thoroughly thrashed out and the methods carried to a logical conclusion without *undue expense* as consistently as they were on that road.

On the larger railroad systems of the West, similar methods have been and are being evolved, but there are still thousands of miles of railways being located in the old-fashioned way, which does not prove, by the actual elimination after thorough examination of all the other possible routes, that the line finally selected is *the best line the country affords* under the governing conditions.

The thanks of the author are also due to the American Society of Civil Engineers for the use of several of the plates, originally accompanying his paper on "Methods of Location on the Choctaw, Oklahoma & Gulf R. R., to the Engineering News, Engineering Record, Mr. John C. Trautwine, Jr., Mr. H. H. Filley, and the Chief Engineers of various railroads, for information and drawings, credit for all of which, it is believed, has been given in the proper places in the text; and last, but not least, to the late A. M. Wellington, whose "Economic Theory of Railroad Location" is still the standard for that phase of the subject, though it is hoped that some one with adequate opportunities will take the matter up at some not too far distant time and bring the subject up to date and in accordance with modern practice

and the most recent tests and data affecting it. The appointment of an especially strong committee of the American Railway Engineering and Maintenance of Way Association, whose first progress report was recently presented, is certainly a step in the right direction which deserves every commendation and encourages the hope of its further continuance, especially in view of the fact that many of its members have special facilities for the acquisition of the necessary data in accordance with present conditions.

F. LAVIS.

New York, October, 1907.

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INTRODUCTION.

The writer having been connected with surveys for the location of railroads for several years, both in the United States and in South and Central America, has been impressed by the wide variation in methods of conducting these surveys adopted by different men and railroad companies; and to a great extent by their general assurance that the methods of each were right; as well as by the fact that while there has been much written on the theory of railroad location there is very little on the actual field practice, and details of methods of location in the field.

While, of course, there must be a somewhat wide latitude in methods to adapt them to varying conditions, there seems to be growing at the present time, especially in the West, where most of the railroad location in this country is being done at the present time, what may be regarded as an approach to a standard in this work, and it is with the idea of defining these methods that the present book has been undertaken; and also to describe, what the party will actually have to do in the field, the actual details of work, not only in making the surveys, but in the production of the maps, profiles and records, and estimates of cost, and data for making the same.

The economics of railroad location, as treated by the late A. M. Wellington, have been barely touched on, the idea of the author being to take the subject up to the point where nine-tenths of the locating engineers (as that title is usually used in the West) have to, that is, with a general route, within more or less wide limits, and a maximum desired grade decided on, the problem being to work out the details of the location between two given points with these conditions given.

This, of course, may be said, with perhaps some truth, to pass

by many of the real problems of location, and while this may be so to a certain extent, the writer believes that there is a need of a treatise which will appeal more particularly to those who are actually doing the work of location in the field, and to the students in college, who wish to become familiar with the actual practice. The broad, general questions which involve the selection of two or more widely separated routes can only be answered by engineers with broad experience, not only in railroad location, but in the operation and maintenance of railroads.

What has seemed to the writer to be a necessity, is a book which will cover the methods of conducting the surveys in the field, after the general route has been decided on; how the party should be organized and handled; short, expeditious methods of getting results; making estimates for comparisons of two or more lines; and how the maps, profiles, estimates, etc., of the final line should be made; and what information they should show.

The writer has attempted to explain the different operations in sufficient detail that they may be understood by students entirely unfamiliar with location surveys, but he has assumed that they have, at least, an elementary knowledge of general surveying and use of instruments. Men with some experience on location may consider that the writer has gone into some of the details with too much minuteness, but all these details are those of actual practice, and are not theoretical considerations necessary for some ideally perfect survey, but have been proven to be necessary for a proper and economical conduct of the work, their omission generally resulting in inferiority and greater cost.

The writer's experience with students fresh from college, or even with a few years' training, starting on railroad location, is, that as a rule they are absolutely ignorant of what is required in actual practice in this work, as indeed is probably to be expected. In four years at college it is impossible to much more than touch on the theory and underlying principles of engineering as a whole, and perhaps some particular branch in detail, and to touch on only those practical details which are of universal application. It is believed that students who expect to be, or who from any cause find themselves engaged in railroad location, will find the details of methods as described in the following pages of some use, especially if they have previously had the privilege of going

through the book under the guidance of their instructor or professor in college. Numbers of men also who have been connected with maintenance or construction departments of railroads find themselves suddenly called upon to join or take charge of a locating party, who, while they have a good, general idea of what is required, and may get results after a fashion, would welcome, the writer believes, a practical treatise on the details of the field work. It is believed also that many engineers who have had experience on location may find in the details of methods, as described, many points in connection with this work which will tend to improve their practice and improve the general standard of the work in connection with such surveys, and it is hoped that the chapter on Estimates will furnish a guide at least for the determination of quantities and costs, where other data especially applicable to some special case are not required or available. No attempt has been made to describe in detail methods of running or calculating curves, as men on whom these duties devolve, on a locating party, should have learned them elsewhere.

In general, the methods described are based on the practice of the Choctaw, Oklahoma & Gulf Railroad, now part of the Rock Island System, and were described in much less detail in a paper by the author, read before the American Society of Civil Engineers, in December, 1904, and published in the Transactions, Vol. LIV, p. 104: (1905).

Mr. F. A. Molitor, M. Am. Soc. C. E., was Chief Engineer of this road, and Mr. E. J. Beard, M. Am. Soc. C. E., was Principal Assistant Engineer, to both of whom the writer is greatly indebted for information and suggestions, as well as for maps and other drawings.

This railroad, located chiefly in Arkansas, Indian Territory, and Oklahoma, runs through a very rough, broken country; at times approaching a mountainous character, and as a rule low rates of grades (0.5% and 0.6%) were desired. This kind of country involves, often and more continuously, greater difficulties to a locating engineer than much mountain country.

The mountain location with its viaducts, tunnels, horseshoe curves, loops, etc., generally appeals to the layman as the highest example of the skill of the locating engineer, as, indeed, in some

instances it is; but the larger part of the so-called mountain location does not call for the skill, especially in reconnaissance, that does the location of low grade lines through rough, broken, rolling country, and in the words of the late A. M. Wellington, the skill of the railroad engineer is most often shown by the imposing bridges, high embankments, deep cuts, long tunnels, etc., *which he does not build.*

Reconnaissance in a mountainous country generally develops a more or less low pass, which is the controlling point in the line, provided proper approach valleys can be found (and as a rule the lowest pass has the best approaches) the remainder of the work requiring only the detailed surveys of a very narrow range of country and the proper projection of a line, it being generally necessary simply to make the best of the one line there is, whereas the location of a low grade line with good alignment through such a country as that described, most often and continuously calls for the examination of a wide range of territory, and the comparison of several lines, sometimes widely separated, before the proper line can be determined.

In general, however, the methods of conducting the surveys should be the same, whatever the country, varied only as to minor details, and it is believed that a thorough understanding of the principles involved and methods used on these surveys will serve as a useful precedent foı work in any kind of country and that details can be modified to suit the particular case in hand. No hard and fast rules can be advocated for railroad location. No two lines are alike; topography is never the same; and nothing will take the place of experience, good judgment, and much hard work.

The writer has endeavored to show where time and money may be saved by avoiding unnecessary refinements and an unnecessary degree of accuracy in conducting such surveys, but he must not be misunderstood as advocating inaccurate surveys or careless, slip-shod work of any kind. This caution may be especially necessary to any students or younger members of the profession who may read this book, and if a man is in doubt he should always err on the side of accuracy. At the same time locating and building railroads is a business proposition, which is expected to pay, and money spent on unnecessary refinement and accuracy

of surveys or maps, over and above that necessary to get the final result—*the best line the country affords*—is money wasted. Cheapness, in any form, is not advocated; true economy is.

The writer believes in good salaries and good living, but the engineer to expect this must be able to save the extra cost of his salary and camp expenses over that of an inexperienced man by so conducting the survey that the cost of the final line, staked out on the ground, will be the least possible, compatible with the results obtained.

Another point is, that it is not always the good fortune of engineers to have at their disposal, the equipment, both of men and material, as well as carte-blanche in regard to time for *necessary* surveys, as was given the writer (as well as other locating engineers) on the C. O. & G. R. R. This was not extravagance but true economy, and only what the writer believes necessary to obtain the best results; still, for some time to come, perhaps always, railroad engineers will have to work at a disadvantage at times, lacking men, equipment, or time, or all, so that they must be prepared to get the best results possible with what they have to do with. It is all the more necessary therefore that they should know what the best results necessitate and approach the ideal as closely as possible.

There are probably many old locating engineers, many who have done excellent work with much less equipment and fewer men, who will hold up their hands in horror at such an organization and equipment as is advocated. No one can for a moment deny the excellence of the work done by some of the older locating engineers under the conditions which they had to meet, and because a railroad does not meet the conditions of to-day it is no argument that it was not well and economically located at the time it was constructed; at the same time it is a well-known fact that there have been and are still being built hundreds of miles of railroads, which, because of faults of location, fail to earn dividends, or, at least, fail to earn as much as they should had they been properly located with a view to their economical operation. Whether the fault was with the locating engineer, or with the conditions imposed upon him, it should be plain that other methods than those of the past are necessary to meet changed conditions. Scientific methods should be applied to the conduct

of location, as well as to the design of bridges, terminals, locomotives, etc., as on a proper location, or otherwise, the future of the railroad is almost entirely dependent.

The author has endeavored to make the explanations clear at each stage of the work, but realizes the difficulty of remembering even all the points which have come up in his own work and among the men with whom he has been associated, which have required explanation, and he will be only too glad to hear at any time from those, especially the younger members of the profession, to whom the explanations are not clear, not only that he may help them should they desire it, but that the omissions may be corrected.

CHAPTER I.

RESUME OF METHODS AND EXPLANATION OF TERMS.

The location of a railroad is generally divided into three operations:

The Reconnaissance.—A rapid, thorough examination of the country through which the proposed road may pass, to determine, in a general way, the route, the principal controlling or governing points, and the general resources of the country.

The Preliminary Survey, the object of which is to make a topographical map of a strip of country through which the final location will pass, and through which runs a sufficiently accurate base line or lines; and on which map the best line the country affords, under the governing conditions, can be projected or laid out, and in such a manner that it can be afterwards reproduced on the ground.

The Location consists in projecting on the map described, the best line the country affords with the governing conditions of alignment and grade; in staking out this line on the ground; obtaining a profile of it and fixing the gradients; determining the character of the material to be excavated and of the various bridges, culverts and other structures; the names of the various property owners; limits of their land, and necessary right of way to be secured; and an estimate of the various quantities of material to be excavated and moved, or used in any way on the construction of the road. The maps and profiles of the line as finally located should present a complete plan and scheme for the construction of the road, with the exception of the details of the structures.

The results to be attained by all location surveys, where a

tentative rate of grade has already been determined, may be briefly summarized as follows:

1st—To establish the fact that a practical line can be obtained with the desired ruling grade, or, if not, what the lowest practical ruling grade will be.

2d—To be sure that the line obtained is such that no other line can be built through the same country, with the same or better ruling grades, with less expenditure, at the same unit prices.

3d—If more than one party is in the field, working on the same line, though on different parts, to keep close control of results from a central headquarters, so that all work may be co-ordinated.

4th—To have on the completion of the survey complete right-of-way maps, estimates of quantities, and cost, showing in detail the exact nature of the work, so that contractors can bid intelligently and work be started at once, if necessary.

5th—To keep the cost of the surveys as low as possible consistent with obtaining the above results.

It may be well at this point to explain briefly for the benefit of the student, the terms used, with which he may not be familiar, and which are in a measure peculiar to railroad work.

The Preliminary Line is a survey line staked out on the ground by driving a stake on the line at each 100 feet, which distance is **one station.** The stakes are numbered, beginning at 0, and continuing 1, 2, 3, etc.; Station 1 being 100 feet from

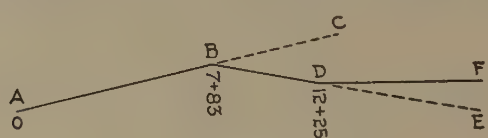


FIG. 1.

0, Station 3, 300 feet, etc. When it becomes necessary to designate a point between two stations, as, for instance, a point 63.4 feet beyond Station 3, this is designated Station 3 + 63.4, and spoken of as three plus sixty-three, forty. The preliminary line consists of a number of straight lines and angles, as shown (Fig. 1).

Calling A, Sta. 0, if the distance A B is 783 feet, the station of B will be 7 + 83; the direction of B D will be determined by the deflection angle C B D, which is recorded as, to the right. If B D is 442 feet in length, the station of D will be 12 + 25, the stationing being carried on continuously from A. The angle E D F, a deflection to the left, then gives the direction of D F. In running lines the stakes are set on line at each 100 feet from A towards B, then B having been selected as a suitable point, a hub (or instrument point) is set there, the distance is measured to it from the last stake driven—Sta. 7—and being found to be 83 feet, a stake is marked 7 + 83 and driven near the hub. On going ahead from B, station 8 is set 17 feet from B towards D, and the even hundreds continued.

Hubs or instrument points are stakes driven flush with the

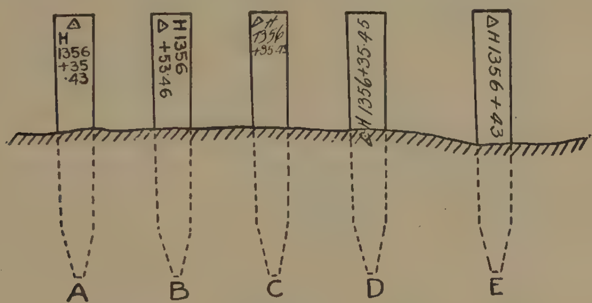


FIG. 2.

ground in which a tack is driven to mark the exact point over which the instrument is set. A stake is driven near the hub with the number of the station marked on it, and it is called a **marker**; besides the letter of the line and number of the station, it should be marked with the sign △ indicating instrument point. Markers should all be driven the same distance from the hub and on the same side of the line, say, 18 inches away, and to the left.

Marking Stakes.—Stakes should always be carefully and clearly marked with good red or blue crayon, and the numbers and letters printed, not written. Figure 2, A and B, shows proper methods of marking stakes, C and D two of the many improper methods, and E the usual method on preliminary lines. Either of the two forms A and B may be used on location, the lettering

and figures being kept well towards the top, so that the stakes may be driven deep in the ground, if necessary. The lettering should never read from the bottom up, that is, the reverse of D and E; there will seldom be plusses at anything but even feet on preliminary, so that more room can be taken up and larger figures made; on location more time is available, and more careful and slightly smaller figures should be used. See also Chapter IV., page 66.

Grades.—In the diagram Fig. 3, which is a longitudinal section through A B C, the points A and C are 10,000 feet apart horizontally, C being 20 feet higher than A, the irregular hatched line, representing the profile of the ground between A and C. If the material in the hill between A and C be removed so that a uniform surface is obtained between them, the straight line joining A and C is said to be a uniform grade, the line is known as the grade line, and as the horizontal distance

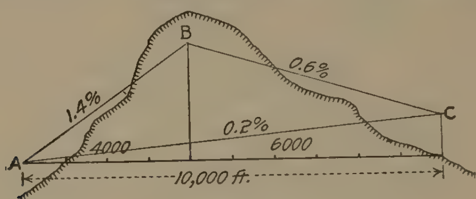


FIG. 3.

between A and C is 10,000 feet, and the difference in elevation 20 feet, the rate of grade is 0.2% (two-tenths per cent.), that is, it rises or falls, as the case may be, two-tenths of a foot in one hundred feet. If the point B, be assumed at 56 feet above A, and 4,000 feet from it horizontally, the rate of grade between A and B will be 1.4% (one and four-tenths per cent.), on the straight line A B, and consequently between B and C 0.6% (six-tenths per cent.)

Grades are sometimes spoken of in terms of feet per mile. especially in European practice, but in America this practice is becoming obsolete, and the common usage is to express them in feet per hundred or per cent. This method is advantageous in that it may be applied to any system of measurement, whether metric or any other, and always expresses the same ratio of rise or fall, and conveys the same impression of rate to the mind, whatever the unit may be.

It is common knowledge, of course, that to build a railroad, the hills must be cut down and the valleys filled; this operation is spoken of as grading, and fixing a grade line on a profile is fixing the lines to which the hills shall be cut and the valleys filled. The grade line usually shown on profiles of railroads during location and construction is generally the sub-grade line, and is a line which is 2 feet below the top of rail of the track after completion, the rail and tie occupying about one foot of this height and the ballast the remainder.

Ruling Grades are grades which limit the weight of trains which can be hauled over an engine division, and are not necessarily maximum grades. (See Momentum Grades.)

Maximum Grade is the steepest grade used on the line.

Pusher Grade is a grade steeper than the ruling grade of the division where a pusher engine is necessary to help trains over it.

Compensated Grades.—As the resistance to the passage of trains is greater on curves than on tangents, this varying directly with the degree of curve, or in other words, the radius; the ruling grade used on tangents must be lessened on the curves, so that the combined resistance due to the curve, and the grade on the curve, will not be greater than the resistance of the grade alone on the tangents.

Owing to varying conditions of track and rolling stock, the exact compensation necessary cannot be exactly determined, but is ordinarily assumed to be about 0.04% per degree of curve, that is to say, with a maximum grade of 0.6% on tangents, a 4° curve, for instance, should not have a heavier grade than $0.6 - (4.0 \times 0.04) = 0.44\%$.

Profiles.—After either the preliminary or location lines have been staked out, levels are taken along each line at each stake and as often as is necessary between, so that when platted they will show a profile of the ground along the line which has been staked out. To facilitate the platting of this line, a paper especially ruled for the purpose and known as profile paper is used.

Location.—The located line is usually the centre line of the proposed railroad, and consists of a series of straight lines and curves. It is staked out on the ground in much the same manner as the preliminary lines, stakes being driven at every one

hundred feet and at the necessary plusses, to mark the line. Curves are referred to, in American practice, by the number of degrees subtended at the centre of the circle by a chord of 100 feet, that is, a 1° curve (one degree curve), 2°—30′ curve (two degree and thirty minute curve), etc., as, for, instance, in

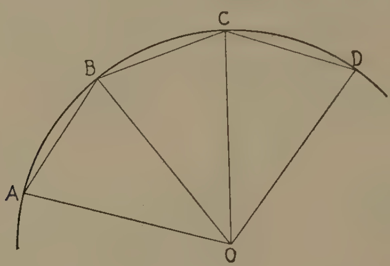


FIG. 4.

the diagram, Fig. 4. If O be the centre of the circle, O A, O B, O C, O D radii, the chords A B, B C, C D each 100 feet, and the angles A O B, B O C, C O D, each 3°—00′ the arc, A B C D would be part of a 3° curve. It should be noted that it is the chord which is 100 feet, and not the arc.

The methods of conducting the surveys in the field, and of presenting the results obtained, as advocated herein, may be summed up briefly as follows:

A Preliminary Line (or lines) is to be run with the idea that it is to be used only as a basis for a topographical survey covering the ground where the final location will lie, and serving as a base line from which the final location may be staked out on the ground. Sufficient preliminary lines will be run to exhaust every possibility, and every line run platted on the map.

Profiles will be taken of all the preliminary lines, which profiles, however, will, as a rule, be used only as a basis for the topography, though, of course, they will be studied whenever necessary, and especially when running grade lines, for what they are worth.

Topography will be taken generally 300 feet on either side of all preliminary lines, except such as show their entire impracticability from the line and profile; five foot contours being located on the ground and platted on the map.

Detail Map.—The map of the line to be platted on a scale of

400 feet to the inch, except where the inability to show sufficient details of topography may necessitate a larger scale; say 200 feet to the inch, seldom larger.

5,000-Ft. Map.—A map of the country through which the line will run and of the country on either side of it, compiled from the best available sources, to be made on a scale of about 5,000 feet to the inch at the beginning of the survey, and all lines, both preliminary and location, to be platted on it to enable the locator to obtain a correct idea of the general direction of his line, and to study it as a whole.

The Locating Engineer to act in an executive capacity entirely, devoting his whole attention to the study of the country, the projection of the line on the map, and its proper location on the ground, this necessitating an assistant in charge of the party in the field, and a field draughtsman to keep all maps, etc., up-to-date. (For modifications where a small party is necessary, see Chapter IX.)

Projected Location.—The location is to be studied and made on the topographical map and not on the ground, after all the information affecting it has been collected, but this is to be done by the man who has made the preliminary surveys, directed the work on the maps, and who is himself thoroughly familiar with every detail of the ground; this line finally laid out on the map being known as the projected location.

A Projected Profile is to be made of the projected location, a grade line carefully laid on it, and quantities (from tables of level cuttings, etc.), figured. Where there is any doubt or possibility of doubt as to the relative value of two lines, a projected location will be made of each, and the cost estimated.

The study of the projected location by those superior to the locating engineer (when there are such) is to be made on the ground at the time the surveys are being conducted, and before this projected line is run in.

The Final Location to be staked out on the ground, so as to reproduce (and better, if possible) the line projected on the map.

A Profile of the Final Location to be carefully taken, and proper bench marks established.

Soundings to be taken when necessary to determine the material in the cuts and for foundations of all structures.

Bridges, Culverts, Etc.—All openings for waterways, bridges, etc., should be located on the ground, and their dimensions fixed there by the locating engineer after the location profile has been taken, and a preliminary grade line drawn on it, this profile being taken on to the ground by the locating engineer and the situation studied on the profile and at the site at the same time.

Quantities will be calculated from the profile, and earth and rock excavation classified as closely as possible from the soundings and personal examinations, and the grade line then finally adjusted to give the best results; the estimated quantities being marked on each cut and fill, and all structures shown on the profile.

Land Lines and names of property owners to be obtained, and recorded on the map; the final located line being inked in in its proper relation to the preliminary line only after it has been run in on the ground.

In all this work it is absolutely necessary that all parts of it should be kept up together, and with the organization outlined in Chapter III., it will be found feasible to so assign the men that any part of the work which lags behind can be brought up-to-date.

CHAPTER II.

RECONNAISSANCE.

The manner of conducting the reconnaissance varies considerably, according to the information desired; from a rapid ride on horseback, or in an open vehicle, through the country, to a more or less detailed examination with the transit and stadia or even the wye-level. In any event, the best available maps of the country through which the line may run (notably in the United States, the maps of the United States Geological Survey, where issued) are examined and a probable route or routes selected. The better the maps available the more closely should this approach the final location. Through settled country, towns will likely be the governing points; through sparsely populated country, the topography, or, in other words, the drainage system and necessary summit-crossings will govern. The governing, or controlling points of a line are those points through which of necessity the line must pass; as for example: the lowest available pass in a range of mountains, or certain towns between the termini.

In the preliminary selection of a route, the financial interests of a proposed new road; or the directors, and traffic officials of an existing road, to which an extension or branch is to be added, will have probably as much to say as the engineer. It is at this stage of the proceedings that what may be called the preliminary reconnaissance is made, the object of which is ordinarily very general, and the results of which are generally made the basis of a report to the officials of the company on the character of the country, probable character of the road, i. e., alignment and grade, rough estimate of cost per mile, and volume of traffic, immediate and future; and on this report a determination is generally reached as to whether further surveys should be made.

This phase of reconnaissance, though of the utmost import-

ance to the future of the road, will not be further touched on here, as ability to conduct such a reconnaissance and make a proper report, is an art, proficiency in which can be only the result of extensive experience, not only on location surveys, but also of the operation and maintenance of railroads, and involves a discussion of the theory of railroad location beyond the purpose of the present work.

The second phase of reconnaissance may be called reconnaissance for detail, and this is what will be generally understood by the term reconnaissance when referred to hereafter. It is the reconnaissance made by the locating engineer, to familiarize himself with the details of the country and determine what portions shall be covered by the preliminary surveys.

It must be thoroughly understood by the student that the problem confronting the locating engineer is not the location of any line through a given country, but the location of the best line; such a line *that no other line can be built, through the same country with the same, or better ruling grades, with less expenditure at the same unit prices.*

The location of a line involving the smallest cost of construction is by no means the only desirable result to be obtained; economy of operation plays an important part, and hence Mr. McHenry's* definition of engineering, which applies especially to railroad location, that "Engineering is the art of making a dollar earn the most interest." Therefore, of two lines even with the same ruling grades and maximum degree of curve, the one which costs the least to build may not be the most economical, because on account of a larger total number of degrees of curvature, or larger total rise and fall, or both, or a greater length of line, it may cost so much more to operate, that it will not earn as large a rate of interest on the money invested as the other.

In comparing any two lines the cost of construction can be closely estimated from the results of the surveys; but in order that the comparison may be complete, a certain probable traffic must be assumed, and the effect on the cost of handling this, of the curvature, rise and fall, rate of grade, etc., estimated,

*Engineering Rules and Instructions, Northern Pacific Railway. E. H. McHenry.

and proper allowance made therefor, as also for any additional cost of maintenance of one line over the other, as see further Chapter VIII.

The reconnaissance for detail may be divided into two parts. The first, a rapid, thorough examination of the country by the locating engineer (the man who will actually have charge of the party in the field), that he may familiarize himself with the general broad features of the country, the scheme of drainage, the various roads and trails, camping places, etc. The second, the true reconnaissance for detail, which will usually proceed with the survey, being kept only sufficiently ahead of it to determine where the preliminary lines should be run.

The desirability of arranging for a preliminary trip over the line by the locating engineer, before the party gets into the field, can hardly be too strongly emphasized, as the knowledge of the general situation and of the country, thus obtained, is invaluable in planning the work of the party. It is a too general practice to start a locating engineer out with a party, and because either it is not properly organized or equipped, or because there is no competent assistant who can take charge of it in his absence, have him tied down to details of the surveys, so that he never sees anything a half a mile away from the line he is running, and often spends the time of the party and consequently the money of his employers doing a good deal of unnecessary, unprofitable work.

As stated clearly by the late A. M. Wellington, the reconnaissance should be of an area and not of a line. The whole range of country between two governing points, which may be ten miles apart, or a hundred, must be thoroughly examined and its general characteristics, especially the drainage, thoroughly familiarized to the locating engineer.

This first reconnaissance may be made on foot, on horseback, or in a light open wagon. This also depends on the country. Reconnaissance on foot should only be resorted to where the country absolutely forbids the use of animals, which is very seldom, or for short distances for details. The man on foot is apt not to cover a large enough range of country, and his physical inability to do this often leads to neglect of the exploration of a sufficiently wide range to determine the best

route. Where at all possible, a light spring wagon with a driver and a pair of horses or mules is the most convenient; a small roll of bedding and supplies can then be carried along, and the team left at any convenient place and short explorations made on foot, or on a led saddle horse, and, if necessary, camp can be made wherever night overtakes one.

All the energies of the locating engineer should be devoted to the study of the country, and any aids to transportation he can avail himself of should be obtained. If the country can only be properly examined by walking over it, he should walk; but if he can save that energy and time and devote it to the study of the country, the result will be better work and less final expense.

If the party is to live in camp, one of the important things the locating engineer should arrange on this first trip will be the places where supplies, i. e., provisions, etc., may be obtained. In some cases, all supplies are bought by the railroad and forwarded, but it is more often the case that the locating engineer buys his own. It will usually be found much more economical to arrange with as few dealers as possible, preferably wholesale, and buy all supplies from them in as large units as practicable. Wherever possible buy in unbroken packages, as for instance, flour or sugar by the barrel, and canned goods by the case. Many engineers, unfamiliar with problems of the commissariat, make the mistake of buying their supplies in small quantities, thus increasing the cost as much as 10% or even 20%. A credit should be arranged with each dealer, so that bills may be paid at the end of each month, thus avoiding the necessity of keeping large sums of money in camp, or sending them with the teamster who gets the supplies.

On the preliminary trip, observations of the general topography of the country should be taken to supplement the maps already on hand, and especially of the local names of various places, streams, hills, roads, etc.

By keeping a close record of the time of passing all points which can be identified, a very close estimate of their distance apart can be obtained, and this may be supplemented by compass observations for direction. This presupposes, at least, some kind of a map of the country, and there is very little of

the world now which is not mapped to show at least the main drainage. If no maps are available the first reconnaissance should be by stadia.

Figure 5 shows a page of the writer's note book as used on a reconnaissance made by him through Indian Territory, where at that time the only maps available showed only the section

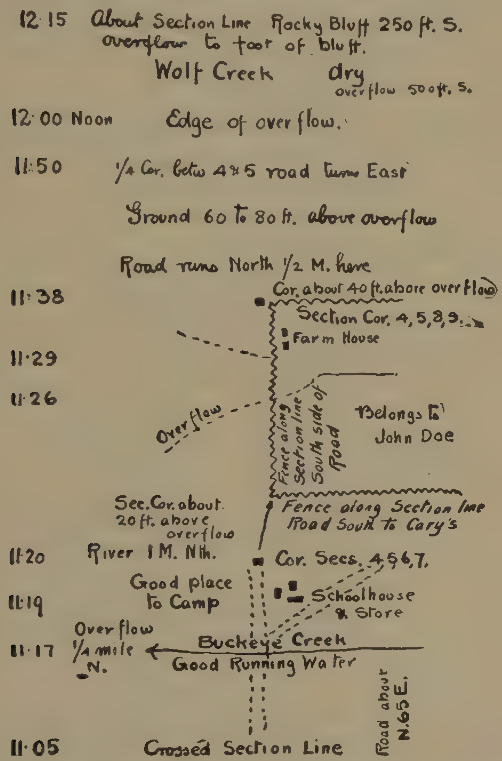


FIG. 5. TYPICAL PAGE OF RECONNAISSANCE NOTE BOOK.

lines and main drainage. With that, however, and by being able to pick up the section lines fairly easily, though fences were rare and only the corners and quarter-corners were usually marked, enough information was obtained on a rapid reconnaissance, where about 120 miles were covered in 4 days, to fill out the map, a part of which is shown in Fig. 6. See also Fig. 28.

Different instruments for approximating distances, directions, and elevations, on reconnaissance have been advocated from

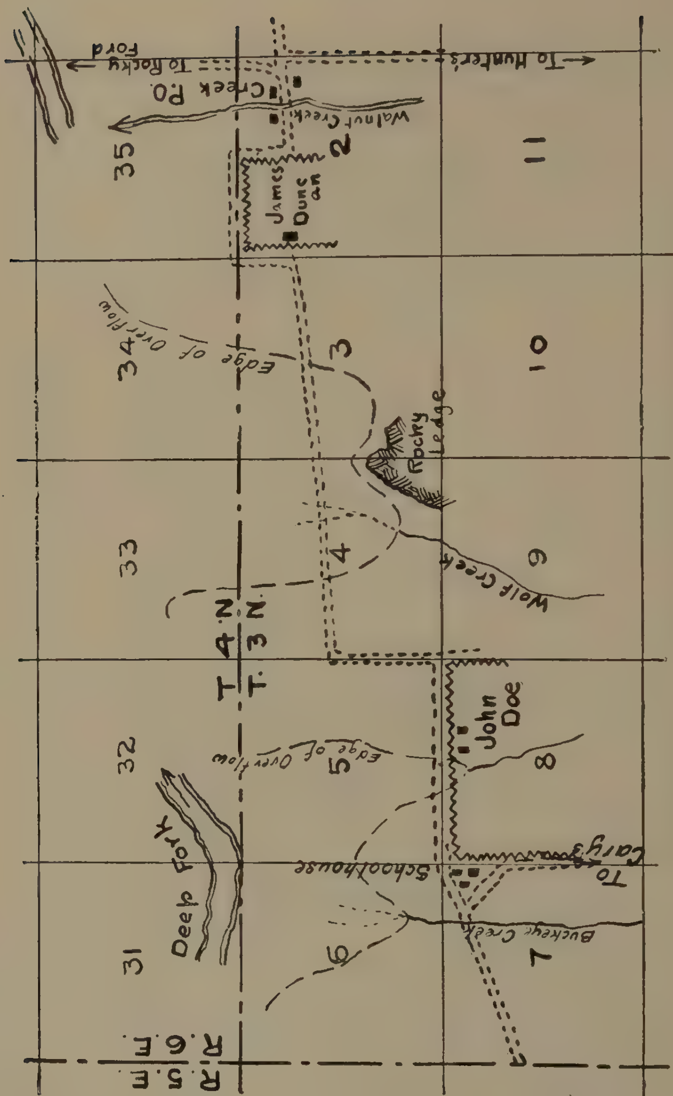


FIG. 6. FINISHED MAP AS DRAWN FROM NOTES AS SHOWN IN FIG. 5.

time to time, but the writer believes the hand level and prismatic compass the only ones of any real value, and that somewhat limited.

Among other instruments, the barometer, both mercurial and aneroid, has received a great deal of attention; but the writer believes that with the increasing availability of reliable maps, the use of any instruments other than those indicated in the preceding paragraphs is being abandoned; or even, and perhaps especially, if no maps at all are available, if any more detailed reconnaissance than that previously indicated, as shown by Fig. 6, is required, the stadia should be employed. At best, the barometer gives only approximate elevations; even if they were correct, they would be of little use without a good idea of the distance and alignment available to reach them; with two, or at most three men, a rapid stadia survey can be made at the rate of six or eight miles a day in almost any kind of country, which will give the experienced locator all the information he needs of the distance, the alignment, and the elevation; all three being necessarily functions of the rate of grade required to surmount a given elevation.

Where the available maps indicate a choice of routes, this first reconnaissance will in many cases enable the locating engineer to eliminate some as entirely impractical, and avoid the necessity of actually making detailed surveys of them.

In heavy timber and mountainous country much time and money will be saved by making the preliminary explorations with a small stadia party, as indicated above, and it will probably be found economical in the long run in almost any country.

"It should be the effort of the engineer to first ascertain the position, character, and limiting effects of controlling points, natural and otherwise; afterwards connecting such points most advantageously, and finally connecting intermediate details to the best advantage."*

While the reconnoissance should enable the locating engineer to eliminate certain entirely impractical routes, the following words of caution of the late A. M. Wellington,† should be taken to heart by all: "There is nothing against which the locat-

*E. H. McHenry, Rules for Railway Location, N. P. Ry.
†Wellington's Economic Theory.

ing engineer will find it necessary to be more constantly on his guard than the drawing of hasty and unfounded conclusions, especially of an unfavorable character, from apparent evidence, wrongly interpreted; if his conclusions on reconnaissance are unduly favorable there is no great harm done, nothing more at the worst will ensue than an unnecessary amount of surveying; but a hasty conclusion that some line is not feasible, or that further improvement in it cannot be made, or even sometimes, often very absurdly, that no line of any kind exists than that one which has chanced to be discovered. These are errors

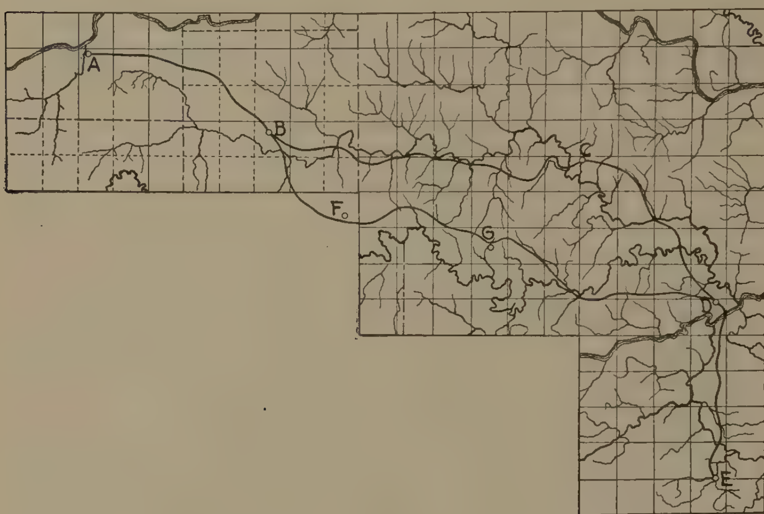


FIG. 7.

which may have disastrous consequences. On this account, if for no other, the locating engineer should cultivate and habitually preserve what may be called an optimistic habit of mind. He should not allow himself to enter upon his work with the feeling that any country is seriously difficult, but rather that the problem before him is simply to find the line, which, undoubtedly exists, and that he can only fail to do so from some blindness or oversight of his own, which it is his business to guard against."

As an example of the preliminary stages of the work, the following account of an actual experience may be of value. It

had been determined to build a line between A and E, Fig. 7, B and D were towns of considerable importance and were governing points. Parties were started at A and E working towards each other, as were also parties at B and D. Between B and D there was a choice of two routes, a valley route via C, a town of considerable importance, and a ridge route via F and G, two small towns which, however, held possibilities of growth. This much was easily determined by the inspection of the available maps and a general knowledge of the country. The preliminary reconnaissance indicated the line via F and G as the more feasible, provided the ridge could be surmounted by the proposed grade, which it was determined should be not over 0.6%. Conditions of traffic were such that unless a line could be built at reasonable cost at about that rate of grade it would not pay.

The parties at B and D therefore were instructed to try the ridge route first, using 0.6% maximum grades compensated for curvature, which latter it was preferred should not exceed a maximum of 4°.

It is at this stage of the proceedings that the locating engineer usually takes up the problem, and in this particular case the writer was assigned to the country between B and G.

On being organized the party proceeded by rail to the point nearest the proposed line, at which place teams had already been engaged. The cooking utensils and a preliminary bill of supplies had to be purchased, however, and that and the loading of the teams occupied the remainder of the day of arrival.

The following day at 6 a. m., the outfit was started. Most of the men walked, about one-fourth of them at a time being allowed to ride. Thirty miles over poor roads were covered by 5 p. m., a camping place selected, tents put up and the men were eating supper by 7 p. m. The first stake was driven before 8 o'clock the next morning and the work fairly started. This is not noted as an uncommon occurrence, but as everyday practice.

It is advisable, where possible, for the locating engineer to take a trip over the proposed line before the party gets into the field, but this cannot always be done, as in the particular case referred to. The preliminary reconnaissance, however, had indicated the location of the first camping place and the first

work to be done. The party, therefore, was immediately set to work under the direction of the assistant engineer, while the writer made a more careful reconnaissance over that part of the line assigned him, making the round trip of approximately 120 miles in four days. The trip was made in an open spring wagon; observations with hand-level and compass were taken, and a full sketch was made of the road, showing all branches from it, stream crossings, houses, of which there were few, sketched topography and all the local names that could be learned.

Distances were estimated very closely by observing the time of passing all points, which could be identified, such as section corners, houses, fences, streams, etc. Figure 5 shows a page of the notebook used, and Fig. 6 a portion of the completed map. The country covered by this reconnaissance had been laid out in sections by the United States Public Lands Survey, so that the translation of the notes, as shown by Figs. 6 and 28, was a comparatively simple matter, assuming, as was the case, that the speed of travel was nearly uniform. For instance, at 11:20 the corner of sections 4, 5, 6 and 7 was passed, and at 11:38 the corner of 4, 5, 8 and 9; these points could be definitely located on the map, the distance known and therefore the rate of travel calculated, intermediate points interpolated, and so on. The result of this first reconnaissance did little more than acquaint the writer with the general features of the country, especially the drainage system, familiarize him with the main roads and trails, location of the various settlements, sources of supplies, camping places, and of water, etc., and to outline a general plan of campaign; leaving the detailed reconnaissance to be made later, just ahead of the transit party, though the general idea of what had to be accomplished and how the problem was to be attacked had been formed in his mind. Arrangements had already been made at B for supplies, and during the trip while at F and G, arrangements were made with the local dealers so that when it became more convenient or necessary to send to that end, the teamster could go there with his orders and get them filled, the bills being payable by cheque at the end of the month, thus obviating the necessity of keeping large sums of money in camp.

The surveys were then proceeded with, but it was found impractical to get on the ridge at either end with a 0.6% grade, and a reasonable line. At this point, if there had been some particular reason for getting over the ridge or on to it, it would have been necessary to decide whether a higher ruling grade should be adopted for the whole line, or whether pusher grades should be adopted at these points. But other reasons influenced the decision to abandon the ridge line and locate the line via C. Instructions were issued to this effect therefore, and the line was finally located on this route.

It may appear at first sight that this was a place where a stadia survey with a few men would have been the most economical method to use, and under certain conditions this would have been so. Certainly the stadia would have demonstrated the impracticability of getting on to the ridge with the desired grades, and the information would not have cost as much money as the surveys actually made did, but there were other circumstances connected with the work which it is not necessary to discuss here, which made it advisable to conduct the work in the manner described. This will be found to be often the case (in fact, more often than otherwise) that circumstances compel the engineer, and especially the railroad engineer, to adopt other methods than those he knows to be the best, but this should in no wise prevent his acquiring the knowledge of the best methods and using them whenever possible, in any event getting the results by whatever method used.

The reconnaissance for detail should proceed with the rest of the work of the survey, being kept sufficiently ahead of the transit party, so that the locating engineer is at all times thoroughly familiar with every detail of the country through which the preliminary lines are being run. It is now usually the practice to provide an assistant locating engineer on the surveys, thus leaving the locating engineer free to examine the country in detail ahead of the party.

On his first trip over the line the engineer can only become generally familiar with the lay of the land, and form only general ideas; before he can say that he has the best line the country affords he must be familiar with the country in detail, so that he can, at any time, call up in his mind's eye the whole area

between his starting point and his objective and know particularly where every little stream comes from and goes to; and it is this study which must be carried on from day to day, ahead of the party, while they are working out the details and preparing the map on which he can project his line.

In connection with this work, the principal difficulty will be found in conveying to the assistant the knowledge of the country the locating engineer has accumulated in his explorations of it, or, at least, that part of his knowledge which it is necessary for the assistant to have in order to intelligently carry out his work. It must be remembered that the transit party will run from two to six miles a day, depending on the nature of the country; and it may not be convenient for the locating engineer to be with them at any time, so that in order to avoid wasting time, and that full advantage may be taken of the knowledge of the country which the locating engineer should have obtained, it is necessary to have full and ample notes for the assistant engineer. Nothing can be better in this respect than plenty of sketches, properly numbered and noted.

The writer had usually used a block of paper of fairly good quality, that ruled in small squares by faint blue lines preferably, as the squares aid considerably in sketching. This is more convenient than a note book as the sheets can be torn off as used and given to the assistant, or, better still, a loose leaf book in which the sketches may be made and afterwards as necessary transferred to a similar book used by the assistant and so kept intact and always available.

These sketches which, at times, may be quite rough, should show plainly the general topographical features of the country, so that the line desired can then be readily shown on them, and in order to avoid unnecessary work they should be in sufficient detail so that the assistant, who, it must be remembered, will probably not have seen the country at all, can readily recognize the different features of the country controlling the line as he comes to them.

The writer usually carries a small axe in a sheath, with which trees may be blazed or marks left to indicate certain points which it may be desired to note, and a supply of strips of red and white cotton cloth, etc., which will be found very useful to tie to

trees and shrubs or to stick up at various points in the open country so that the party can follow the line with little trouble or vexatious delays.

It may perhaps be advisable to reiterate the writer's opinion as to the value of the stadia for reconnaissance for railroad surveys to the absolute exclusion of all other forms of instruments. Stadia surveys can be made as fast as the country can be covered on foot, and absolute records of distance, direction and elevations obtained. Since writing the preceding part of this chapter the writer's attention has been called to a book by an English writer, in which methods of using all kinds of pocket instruments for preliminary railroad surveys are described; mercurial and aneroid barometers, passometers, odometers, boiling point apparatus, sextants, range finders, etc., etc., ad lib. Many of these things have their uses for explorations of unknown and unmapped countires for map work, but the writer has never been able to see the use for railroad work of knowing elevations as shown by barometers without knowing also distances and directions. The compass and odometer or passometer might give some approximation of these latter, but the stadia will give them more accurately and probably more rapidly. The stadia work can be kept within the narrowest limits or may be extended to any desirable degree. With five or six men if necessary a good map of very rough country can be rapidly outlined and at the minimum expense. Stadia tables are given at the end of the book. The writer does not believe the plane table practical for this kind of work. The field work with a transit can be carried on in almost any but the worst kind of weather, and the notes platted at any convenient time or place.

CHAPTER III.

ORGANIZATION AND EQUIPMENT.

The organization and equipment of locating parties will, of course, vary with the locality in which they are engaged. It is the general practice, however, except in a very few of the northeastern States, to provide the parties with a camp outfit, more or less complete, according to the policy of the road, its financial status and the facilities of transport. It is the author's experience that the completeness and quality of the survey is very apt to vary directly with the completeness and quality of the outfit supplied.

On the C. O. & G. R. R., the organization of locating parties was as follows, the salaries noted being approximately those generally paid in the west on this class of work:

Locating Engineer	$150 to	$175 per month
Assistant Locating Engineer	115 to	125 per month
Topographer	90 to	100 per month
Transitman	90 to	100 per month
Leveler	80 to	90 per month
Draughtsman	80 to	90 per month
Rodman		50 per month
Head Chainman		50 per month
Rear Chainman		40 per month
Tapeman		30 per month
Back Flagman		30 per month
Stakemarker		30 per month
Axeman (3 to 5 as necessary)	25 to	30 per month
Cook		50 per month
Cook's Helper		20 per month
Double Team and Driver (furnish their own feed; driver boarded in camp)	65 to	90 per month

Each man was supplied by the company with subsistence, required to provide himself with an army cot (see Fig. 8) and sufficient bedding, and advised to provide a substantial canvas covering for the latter; an ordinary canvas wagon cover costing from $3.00 to $5.00 being the most easily obtainable, and most satisfactory. The writer has always insisted, as far as possible, that men should be properly equipped before starting

out. The army cot takes up the least space of any, both when in use and when folded, and if the bedding is properly protected much cause for grumbling is removed on account of its becoming wet or dirty in moving camp, or through the tents leaking slightly, as the best will do at times. Men should not be allowed to sleep on the ground except where, as in the northern woods, good bedding of spruce or fir boughs can be obtained, stories of old timers to the contrary, notwithstanding.

Each man's baggage, besides bedding, was limited to about what could be packed in an ordinary suit case. With the large party and equipment carried, it was found that three good double teams had all they could do, to move the outfit, and when the

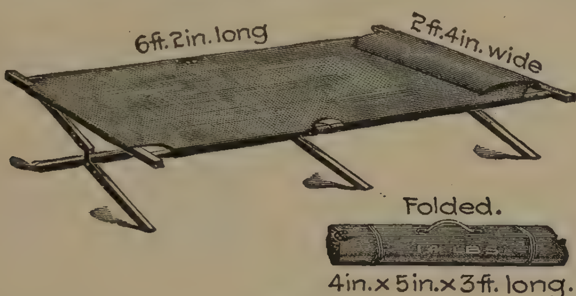


*FIG 8.

roads were in bad condition it was sometimes found necessary to use an extra team.

Each wagon was required to be provided with a heavy canvas cover and at least one spring seat. The prices for teams varied with the locality and the season of the year. A saddle horse was provided for the locating engineer and an arrangement was made with the head teamster to care for and feed him. The camp equipment was as follows, and may be considered as being very complete:

1 Office tent with fly, 14x16 ft.
3 Tents, 14x16 ft.
1 Cook tent, 16x20 ft.
3 Drafting and office tables.
½ doz. iron camp chairs.
Stationery and map chest with necessary stationery, blank forms, drawing paper, etc. (Fig. 13).

DINING TABLE.

3 doz. agate-ware dinner plates,
3 doz. agate-ware dinner cups,
2 doz. agate-ware dinner saucers,
2½ doz. steel knives,
2½ doz. steel forks,
2½ doz. plated teaspoons,
1½ doz. plated dessert spoons,
1 doz. plated tablespoons,

*Courtesy Little Rock Tent and Awning Co.

½ doz. tin salt boxes,
½ doz. tin pepper boxes,
¼ doz. 2-qt. round agate-ware pans,
½ doz. 1-qt. round agate-ware pans,
1 doz. round agate-ware pans, 1 pt,
1 carving knife and fork,
7 yds. oilcloth, 48 in. wide,
3 Standard trestles (see sketch, Fig. 9),
5 boards, 12x1½ in. x 18 ft. (dressed).

COOKING UTENSILS.

1 No. 8, 6-hole wrought iron range,
1 tea-kettle,
1 large cast-iron pot,
1 small cast-iron pot,
2 large frying-pans,
1 small frying pan,
2 griddles,
4 tin pans with covers, 1 gal. each,
2 stew-pans,
1 3-gal. coffee-pot,
1 1-gal. teapot,
4 dripping-pans,
6 baking tins for bread,
12 tin pie plates,
2 butcher knives,
1 steel,
2 large meat forks,
1 chopping-knife,
1 meat saw,
2 large iron spoons,
1 soup-ladle,
1 cake turner,
1 flour sieve,
1 colander,
1 5-gal. tin dishpan,
1 5-gal. tin bread pan with cover,
1 chopping bowl,
1 bread-board,
1 rolling-pin,
1 biscuit cutter,
1 nutmeg grater,
1 coffee-mill,
1 spring balance,
6 galvanized-iron buckets,
6 tin dippers (one for each tent, and two in cook tent),
2 can openers,
1 corkscrew,
1 broom,
1 scrubbing-brush,
1 alarm clock,
1 table (same as drafting tables, see Fig. 10).

MISCELLANEOUS.

½ doz. Dietz lanterns,
3 large tin lamps (central draft, round wicks),
2 large galvanized-iron washtubs,
1 washboard,
4 Sibley stoves (4 lengths of pipe with dampers, 12 lengths of plain pipe), (see Fig. 11),
2 water-kegs, 2 gals. each,
6 washbasins.

TOOLS.

1 grindstone and fittings,
1 monkey wrench,
1 pick,
2 shovels,
1 short crowbar,
1 hand-saw,
100 feet manila rope, ¾-in.,
2 hand-axes,
4 chopping-axes,
½ doz. axe handles,
1 bundle sail twine,
½ doz. sail needles,
1 sail palm,
10 lbs. assorted sizes of wire nails,
1 cross-cut saw.

LUNCH BOX (See Sketch, Fig. 12).

2 doz. agate ware dinner plates,
2 doz. agate-ware saucers,
2 doz. cups,
1½ doz. steel knives,
1 2-gal. coffee-pot,
1½ doz. steel forks,
1½ doz. plated teaspoons.

Note.—This equipment for the lunch box was not ordinarily furnished on the C. O. & G. R. R. The writer, as explained later, believes it economy, however, to provide this.

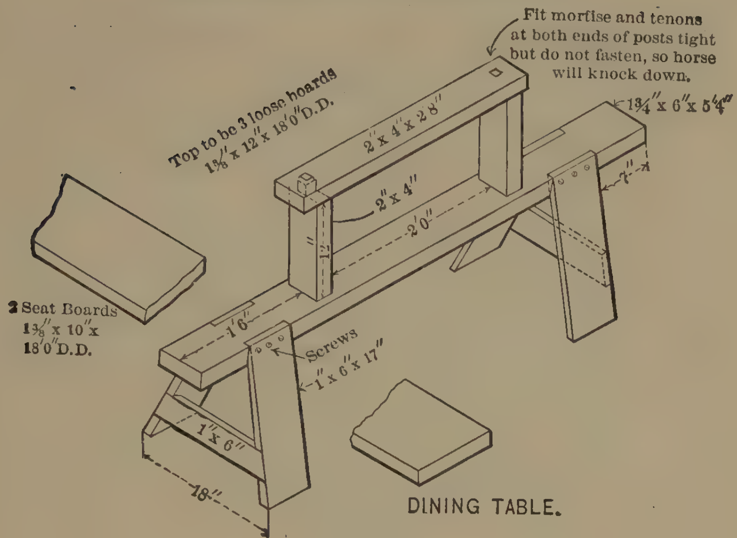

Fit mortise and tenons
at both ends of posts tight
but do not fasten, so horse
will knock down.
1¾" x 6" x 5'4"
Top to be 3 loose boards
1⅜" x 12" x 18'0" D.D.
2" x 4" x 2'8"
2" x 4"
2'0"
12"
1'6"
2 Seat Boards
1⅜" x 10" x
18'0" D.D.
Screws
1" x 6" x 17"
1" x 6"
18"
7"
DINING TABLE.

FIG. 9.

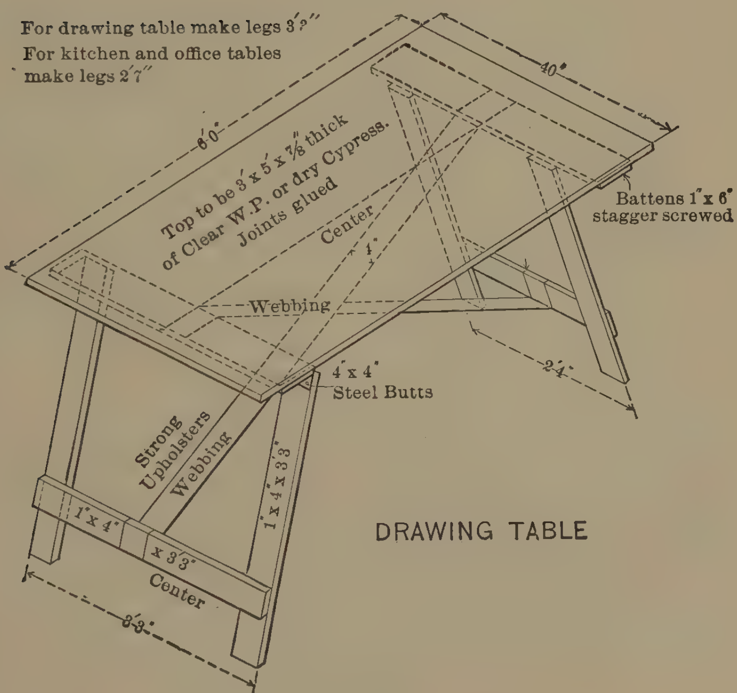
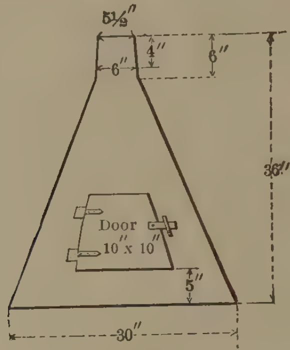

For drawing table make legs 3'2"
For kitchen and office tables
make legs 2'7"
6'0"
40"
Top to be 3' x 5' x ⅞" thick
of Clear W.P. or dry Cypress.
Joints glued
Center
1"
Webbing
Battens 1" x 6"
stagger screwed
4" x 4"
Steel Butts
2'4"
Strong
Upholsters
Webbing
1" x 4" x 3'3"
1" x 4"
x 3'3"
Center
3'3"
DRAWING TABLE

FIG. 10.

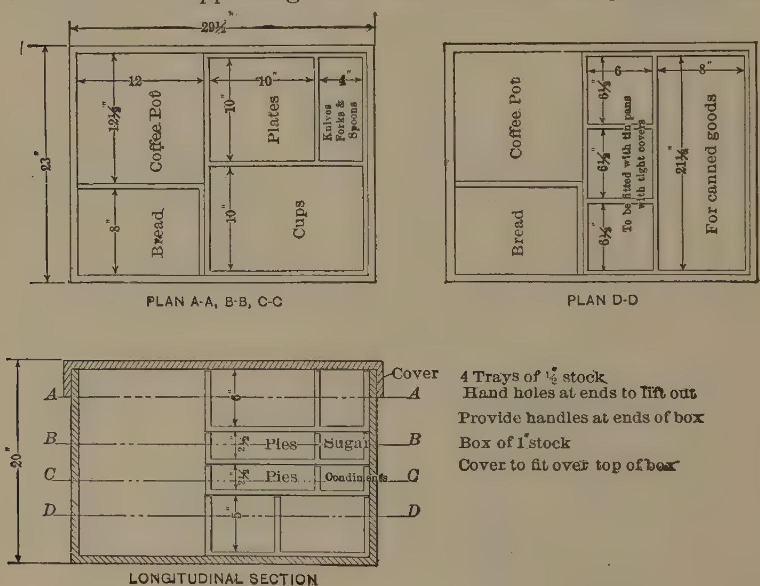
Tents.—The tents furnished were 12-oz. duck, roped on the seams and ridges with ¾-in. Manila rope. They were without



SIBLEY STOVE.
No. 18 U.S.S. (0.05")Sheet Steel.
5 Joints Stove Pipe.
Damper in 1st Joint.

FIG. 11.

ridge poles, four upright poles supporting the centre, and four on each side supporting the walls. Tackle was provided and



LUNCH BOX
FIG. 12.

two single blocks on the front guy rope, there being rectangular door flaps at each end, with substantial leather straps and buckles for fastening them. Leather stove pipe holes, with asbestos filling between the leather, were provided. The office tent had 5-ft. walls; the others 4-ft. (See Fig. 14.)

When the genuine Mt. Vernon army duck can be obtained, 10-oz. duck gives practically as good service as far as life is concerned as 12-oz; the stiffer duck when folded easily cuts and wears in the creases when carried in the wagons. In very hot weather, or in a very rainy country, a 12-oz. fly is desirable. In cold weather with the lighter tents, in sizes above 12 x 14 ft., it is difficult to heat a tent of 10-oz. duck with the ordinary Sibley stove, but, if necessary to provide camp equipment in a cold climate, the whole equipment can be kept down to that size.

Drafting Tables.—The tops of the drafting tables were of 7/8-in. clear white pine, with hinged legs, connected by 4-in. webbing, arranged so that the legs folded flat against the tops. (See Fig. 10.) When moving camp, the tables were placed face to face and tied together, thus preventing injury to the tops.

Dining Table.—The planks forming the top and seats of the dining table are placed in the bottom of the wagon when moving camp, as they take up very little room in the bed of the wagon, and the projection of the planks at the rear provides support for the stacked Sibley stoves and other light equipment. The legs of the lower portion of the horses are so spaced as to straddle the wagon and drop between the bed and the rear wheels. (See Fig. 9.)

Stationery and Map Chest.—It is important that this chest (Fig. 13) should be well and strongly made. The protection of the maps, etc., often the results of the expenditure of thousands of dollars, should not depend on any cheap or temporary expedient, as is often the case. It is not an uncommon experience to be caught in the rain while moving camp, and the best of tents are not always impervious to water. It should be seen to and insisted upon that all maps, notebooks, etc., should be placed in the chest over night, and that it should be set up from the ground on blocking with a clear space of 6 or 8 ins. underneath.

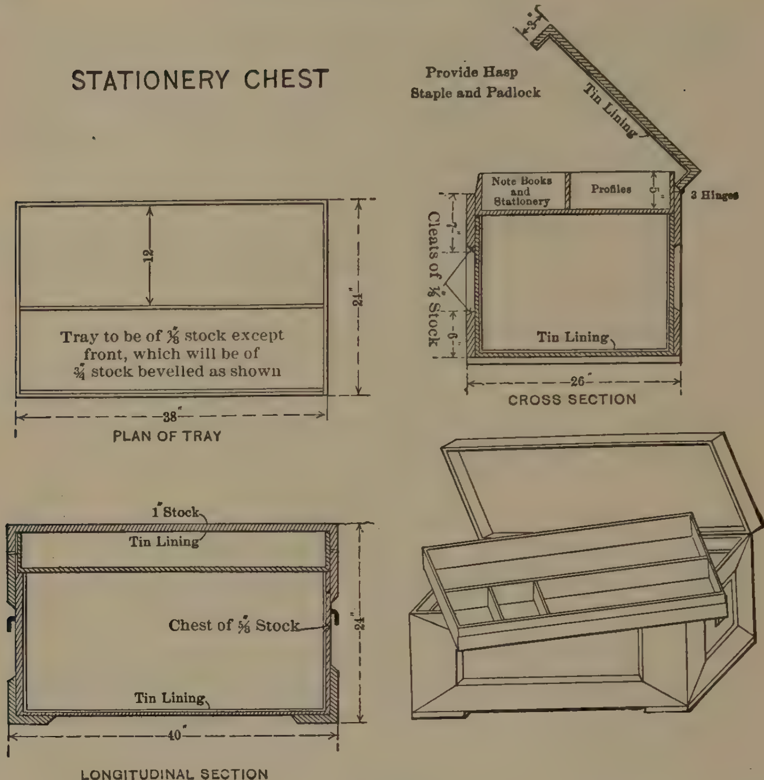


FIG. 13.

Lunch Box.—The midday meal being eaten in the field, a substantial lunch box (Fig. 12) should be provided, with a separate equipment of plates, knives, forks, etc., from that used in camp.

The party should be ready to start for work immediately after breakfast, and should not be kept waiting while the breakfast dishes are being washed to go into the lunch box, nor should they have to wait for their supper while the dishes used on the line during the day are being prepared for use. The lunch box can often be best designed in camp after starting, so that it can be made to fit the supplies purchased.

Some further notes in regard to special equipment, etc., suitable for foreign or tropical countries and special conditions will be found in Chapter IX.

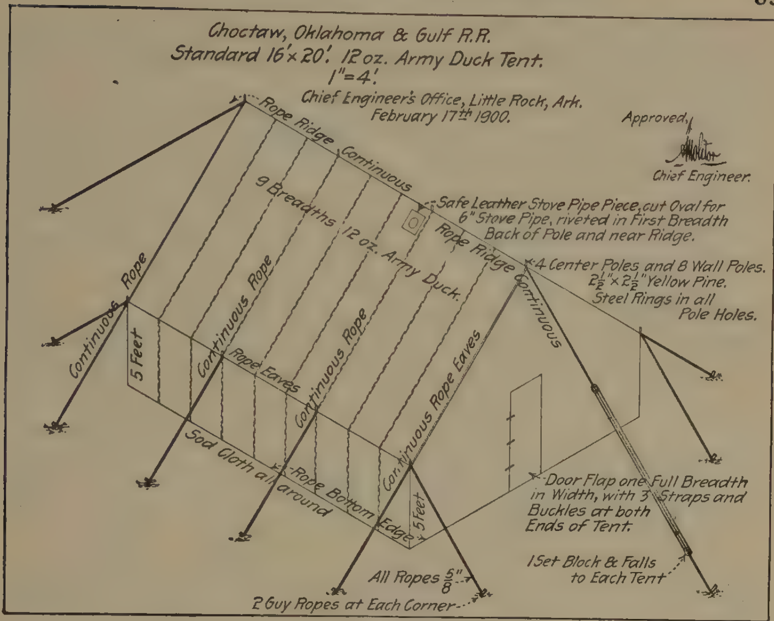


FIG. 14.

Stationery, Etc.—The following list of stationery was supplied, and replenished from time to time as used:

12 transit books,
18 level books,
1 roll tracing cloth, 36 in., imperial, dull back.
12 topography books,
1 roll of profile paper, 24 ins. wide, Plate A,
20 yds. duplex paper,
1 roll tracing paper, 48 in., 10 yds.,
25 yds. tracing profile paper, 24 in. wide, Plate A,
3 quires bill cap,
2 doz. expense account forms,
1 doz pay rolls,
10 yds. cross section paper, 24 in.,
24 estimate sheets,
6 pads letter heads,
1 box large envelopes,
2 doz. figuring pads, letter size to take pen,
1 box small envelopes,
2 doz figuring pads, note size to take pen,
1 doz. HHH pencils,
1 doz. HHHH pencils,
½ doz. HHHHHH pencils,
1 doz. No. 3 Faber pencils,
2 doz Dixon black crayon pencils,
1 doz. penholders,
4 doz. Esterbrook pens,
1 box No. 303 Gillots pens,
1 box No. 404 Gillots pens,
4 doz thumb tacks,
1 doz. Ruby pencil erasers, Faber's No. 113,
½ doz. ink erasers,
1 box Magills fasteners,
3 bottles Higgins' black India ink,
3 bottles Higgins' red ink,
1 bottle Higgins' blue ink,
3 boxes rubber bands (assorted),
2 roller copy books, Bushnell's,
1 book of time checks, form No. 10.
1 box writing pens,
1 bottle writing fluid (copy),
1 bottle photo paste,
1 36-in. steel straight edge, heavy,
1 45° triangle, 12 in.,
1 60° x 30° triangle, 12 in.

The Surveying Instruments necessary for such a survey are as follows:

Transit Party—1 engineer's transit, fitted for stadia work; 1 flat sighting rod, for back sight, 10 ft.; 1 round sighting rod, 8 ft.; 2 100-ft. steel tapes (hoopskirt or band tape); 3 8-oz. plumb-bobs; marking crayons, red and blue; 8-lb. sledge and frost pin in winter; 1 spare axe; 2 brush hooks; 1 fine steel tape, to be kept in camp for checking lengths of tapes in use; 1 stadia board.

Level party—1 Wye level and one level rod, cloth tape and small hand-axe, with sheath and belt,

Topographer—Hand level, cloth tape and 1 10-ft. rod, ⅞″ x 1¾″, joint, with dowel at center graduated in feet.

Axemen—Provide their own axes; the Railroad Company furnishing new handles when necessary.

Much time may be wasted on surveys by improper equipment of instruments. A good transit may cost $250; a poor one can be bought for $150; but the amount saved in the original cost of the instrument will probably be lost during the first month.

The reason, apparently, for providing cheap instruments is that any instrument is subjected to hard usage, and therefore a fine instrument would be damaged much more than a cheaper one. The writer's experience is, that if a competent instrument-man be given a good instrument, he will take any amount of pains to keep it in good order and do good work, whereas with a cheap instrument, notwithstanding all the vigilance of the chief of the party, no care will be taken of it, and any mistakes will be laid to the instrument. Even if care be taken, it takes longer to do good work with a poor instrument than with a good one, and the time the party loses soon makes up the difference in cost. It is economy in many ways to provide an extra transit. Accidents may happen, and it is often convenient to equip an extra transit party, and there are many occasions when an extra instrument may save much time.

The link-chain should be absolutely discarded for any kind of work in any place. The so-called hoop-skirt tapes or band tapes made of steel and graduated at each foot with tenths at each end are the most satisfactory in every way; they will stand very hard usage and pull easily through the brush. An extra tape should always be carried along with the party in the field, in case of breakage, and a tape-mending outfit kept in camp. A very satisfactory arrangement is to have the tape from 0 to 100, graduated at every foot, and an extra foot back of 0, graduated

in tenths. A tested steel tape of good quality, 100 feet long, should be kept in camp, and the tapes used in the field tested at frequent intervals.

Medical Equipment.—The writer has generally provided a small medical equipment, somewhat as follows:

100 5 gr. quinine pills,
100 compound cathartic pills, U. S. pharmacopia,
100 sun cholera mixture tablets, 5 gr.,
100 3 gr. acetanlid tablets, or phenacetine,
100 5 gr. bichloride of mercury tablets,
2 surgical needles, with silk, in sealed glass tubes,
½ doz. rolls of bandages, about 4 in. wide,
1 hypodermic syringe,
20 1/40 gr. strychnine tablets,
20 2 gr. permanganate of potash tablets.

All in a substantial leather case lined with tin.

The Quinine: To be used for malaria, 5 to 30 grains being taken about 4 or 5 hours before the fever or chills start, one or two Compound Cathartic Pills having been taken long enough previously to allow them to act. Don't give quinine during a chill.

Cathartic Pills: 1 or 2 as a dose, in case of biliousness or constipation.

Sun Cholera Mixture Tablets: To relieve diarrhoea or cholera morbus, 1 tablet every hour until relieved.

Acetanlid or Phenacetine: For nervous headache, fever, grippe, colds; 2 each hour until 15 to 18 grs. have been taken. No more than this should be taken at one time, as it acts as a heart depressant. It will often break up a bad cold if taken at the start, before going to bed at night. This is no good for bilious headaches.

Bichloride of mercury, being a deadly poison, should be handled with the greatest of care. It is used as an antiseptic for cuts, etc., and for surgical use.

If any serious wounds need attention, everything which comes in contact with them should be thoroughly sterilized by boiling in a solution of bichloride of mercury—one tablet to a quart of water—before being used, and then not allowed to come into contact with anything not sterilized. If a wound needs sewing, the operator should see that it and all the surrounding flesh is thoroughly cleansed with a solution of bichloride of mercury

(one tablet to a quart of water), his hands and everything being thoroughly cleaned; and soaked in this solution before coming in contact with the wound.

Then the small tubes with the needles and silk may be broken, not before, and the wound sewed up as well as possible, until medical attendance can be obtained.

In case anything more serious than ordinary headache, biliousness, constipation, or diarrhoea occurs, a competent physician should be obtained at once, though every man who is in charge of other men in places where there may be considerable delay in getting medical attendance should familiarize himself with the ordinary first aids in case of injury or illness. Books on the subject can be obtained from any first-class bookseller; *but don't practice medicine as an amateur unless there is no other resource.*

For Snake Bites.—The best remedy to prevent them is by wearing heavy leather boots or leggins up to the knee; very few snakes can strike much higher than a foot from the ground. If bitten, first, tie ligature on proximal side of wound (between wound and heart) if possible, tight enough to stop all circulation to part affected. Make free incisions of wound—several small cuts; wound may be sucked if there are no abrasions of the skin of lips or mouth. The poison, if swallowed, will have little effect, though, of course, this will be avoided if possible.

To overcome depression, and stimulate action of heart, give 1-40 grain of strychnine sub-cutaneously with hypodermic syringe. Injections every 20 minutes *till pulse gets nearly normal,* at the same time hypodermic injections of alcohol (whiskey) to act quickly until strychnine begins to act. *Only enough* alcohol and strychnine should be given to overcome the depression.

Inject 2 or 3 drams 5% solution of permanganate of potash in tissues near wound if poison has not entered system.

Bandage limb downwards from ligature towards wound; repeat several times.

Gradually loosen ligature and allow circulation to start a little, then tighten again, thus allowing the poison to enter the system gradually and in small quantities.

Strychnine in 1-40 grain tablets and permanganate put up for

use in hypodermic syringe can be obtained from any druggist. Dissolve strychnine in just enough water to about half fill the ordinary syringe and the permanganate to make the 5% solution.

Camp Regulations, Etc.—With the organization previously outlined, the men were assigned to the various tents as follows:

Tent No. 1.—Office tent, in which were two (2) drafting tables, and the map chest. Locating engineer and assistant engineer.
Tent No. 2.—Transitman, topographer, leveller, draughtsman.
Tent No. 3.—Head chainman, rear chainman, tapeman, back flagman, stake marker.
Tent No. 4—Axemen and teamsters.
Tent. No. 5—Cook tent; cook and helper. (Dining table, kitchen utensils and provisions).

The locating engineer comes in contact with property owners and residents of the country long before anyone else does; he should always bear in mind that he represents large interests, and he should endeavor to create a favorable impression on those whom he meets, as by doing so he may save the company money when it comes to buying their property, and a favorable or unfavorable first impression may make considerable difference later when the company has to ask for franchises or other concessions. The bearing of the engineer in charge is also reflected all the way down through the party; courtesy to land owners through whose property it may be necessary to run lines should be scrupulously observed, and any damage to crops promptly settled for when a reasonable claim is presented, and care observed to leave all fences in as good or better condition than they were found.

Much of the success of an engineer in charge of location is due to his ability to handle readily the different characters that go to make up the party. Discipline tempered with judgment is, of course, essential, and a certain amount of formality is necessary. Seats at the tables should be assigned to each man in order of his rank, and the men should be required to occupy their proper seats.

The writer has never restricted conversation in any way, provided it was gentlemanly, except that no comments either of praise or blame upon the food on the table were permitted. If anyone had any complaints, they were required to make them directly to the chief of the party, out of the hearing of the cook,

and on no account should the men be permitted in the cook tent, except at meal time.

Frequent inspection of the tents should be made by the chief of the party. The cook's helper should look after tent No. 1, and see that it is kept clean and tidy at all times. Each man should make his own bed, and leave all his things in order before going to breakfast; the men assigned to each tent should be expected to divide the necessary chores between them, to keep the tent in a clean and tidy condition, to get water, and, in winter, to split the wood necessary for the stoves. In sparsely settled country considerable attention of this kind is necessary to insure the cleanliness and health of each man; and the lazy habits of one should not be allowed to cause unnecessary discomfort to the others. On Sunday mornings, unless actually raining, all the bedding, blankets and cots should be spread out on the grass, bushes, or elsewhere, and thoroughly aired. It may seem to many unnecessary to enumerate all these details, but the writer has found that in almost every party there will be some men who will have to be told to do these things, that all should know, and be sharply looked after besides.

The writer's practice has been to have the men called by the cook at 5.30 a. m., breakfast was ready at 6, and a start for the line made at 6.30; in winter, half an hour later. He has always insisted that unless there was some important work to finish, that the men should quit work in time to be in camp by 6 p. m., and that supper be ready by 6.15.

The cook is quite an important member of the party, and cooks in general have earned the reputation of being hard to get along with, especially if they are good cooks. That the writer has had little or no trouble with them he attributes a great deal to the fact that he has always insisted on a certain amount of order and regularity of the meals; and because he allows no one to interfere with or give orders to the cook except himself, or, in his absence, the man in charge of camp. At the same time, that due consideration should be given to the cook in making all arrangements, the fact should never be lost sight of by the chief of the party that *he* is in charge of the camp, and is making a survey for a railroad, and that in the end everything is sub-

ordinate to this; and he must never lose his control of the situation or fail to make all the members adapt themselves to any conditions or circumstances that arise.

The teamsters should be called at least half an hour before the other men, so that they may feed and water their horses and get them harnessed before breakfast, so that as soon as the meal is over they may be hitched up and ready to start immediately for the line. With three teams, two can be used to take the men to their work, the third being kept busy keeping up subsistence, supplies, fuel, etc. In settled country, where supplies can be easily obtained, it may be more economical to employ constantly two teams only, and on moving days hire such additional teams as may be necessary.

When moving camp, an early start is desirable, breakfast should be served an hour earlier than usual, and as soon as it is finished the men in each tent should get their own things and bedding packed, and their tent down and folded as quickly as possible, ready to place on the wagons; by the time they have done this the cook will have his dishes washed and fire drawn. Part of the men can then be assigned to the office tent, and part to the cook tent, this latter being the last down and first up. One man should be regularly assigned to each team as packer, and the same things should go in the same place each trip.

By having breakfast at 5.30 a. m., everything should be packed ready to start by 7 a. m., or a little later, and with fairly decent roads about twelve miles, the usual distance between camps, should be covered and the tents up by 2 p. m. It frequently happens, however, that the roads are bad and muddy, or that it rains after a start is made, hence the desirability of an early start and some leeway for contingencies. The remainder of the day can be spent by the party in checking estimates and in various office work, making stakes, getting firewood, etc. If necessary, and it usually is, some arrangement can be made to keep the topographer and the leveler working in the field on days when camp is moved, as they usually have some work to do in order to catch up.

The site for the camp should always be selected on slightly sloping ground, so that it will drain, and good size ditches should be dug around each tent at once. These ditches should not be

little scratches in the ground, but real ditches, with outlets, and they should be dug immediately camp is pitched.

Stakes.—Stakes used on preliminary lines are usually made in camp from any timber available, which is fairly straight grained. On location good substantial stakes of oak or chestnut only should be used, and made somewhat larger than those on preliminary, faced on both sides, one being used for the station number, the other side being left for marking the cut or fill on construction. Where timber is scarce, laths may be used on preliminary, and 1-in. hard pine boards planed on both sides cut up for location.

Subsistence and Cost.—The food provided should be plain, wholesome, and of the best quality obtainable. As a general rule, fresh meats and vegetables are difficult to get, and canned vegetables, dried fruits, and for meats, hams and bacon will have to be relied on to a great extent. While, of course, the final and principal object of the locating engineer is the location of a line of railroad, the fact should not be lost sight of that good food and enough of it, properly cooked, is a very important factor in keeping up that *esprit de corps* which is absolutely essential to any degree of success in this particular work.

The writer's experience has been that in the Middle West the expense for provisions for such a party should be between $250 and $300 per month. This is, perhaps, a little high if anything, as the writer has always believed that there is nothing within reason in the shape of things to eat which can be obtained in the kind of country through which new railroads run that is too good for the party.

The expense of the parties, as noted in the tables of cost, Chapter VIII., show costs varying from $220 to $250 per month for provisions alone. Opinions on what is proper and what is luxurious vary greatly, but, as with other things, a happy medium should be striven for. Where the whole party is made up of well-educated and trained professional men, with the exception of the axemen, higher standards of living will be expected. Engineers on such surveys average for week after week 100 to 110 hours per week of actual work, as contrasted with 45 to 48 hours for the ordinary business man or office engineer, and the extra cost of providing them with whatever comforts can be reasonably obtained ought not to be objected to.

The following list of groceries covers about all the things usually bought, and the quantities of each ordered each time:

6 hams,
6 pieces of bacon,
50 lbs. fresh beef,
1 case of eggs,
25 lbs. butter,
25 lbs lard,
100 lbs. flour, hard wheat,
100 lbs. flour, soft wheat,
12 lbs. buckwheat flour,
5 lbs. macaroni,
35 lbs cornmeal,
1 cheese, (about 15 lbs.),
12 packages of oatmeal,
10 lbs rice,
100 cakes of soap,
1 gal. of molasses,
1 case condensed milk,
1 doz. tomato catsup,
¼ doz. Worcestershire sauce,
1 lb. of pepper,
1 gal. pickles,
100 lbs. sugar,
5 lbs. baking powder,
2 lbs. tea,
50 lbs. coffee,
50 lbs. navy beans,
25 lbs. lima beans,
¼ doz. vanilla extract,
¼ doz. lemon extract,
1 box of dried prunes,
5 lbs. raisins.
4 doz. assorted canned fruits,
1 case of tomatoes,
1 case corn,
1 bushel of potatoes,
1 kit of salt mackerel,
20 lbs. salt,
1 lb. of mustard,
½ doz. yeast cakes,
1 quart vinegar,

Different methods are adopted by different railroads as to the manner in which locating engineers are supplied with money or the bills paid. Generally, however, the locating engineer buys all provisions, pays the bills himself, taking receipts; and puts the whole thing in his expense account, which is sent in with the receipts attached, at the end of each month.

In some cases the amount of this is forwarded to the engineer as soon as possible after his accounts have been examined and approved, though the most generally satisfactory way is, the writer believes, the method adopted on the C., O. & G. R. R. A running account was opened with each of the locating engineers, sums of money being advanced from time to time by the treasurer, on requisitions O. K.'d by the chief engineer, which were debited to this account; each expense account, on being sent in and approved, being credited to it, and a settlement made on the termination of the surveys.

The author has found it a very useful practice to have a list made out of all the supplies needed in camp, on a large sheet, with a number of ruled columns, the list being on the left-hand edge. The columns are headed alternately "On Hand"—"Received," and a space left for the date. Before the supply wagon starts out the "On Hand" column is filled out from an inventory of the supplies in the cook tent, and then the order made out,

the supplies required being entered in the next column in pencil and checked when the wagon returns. In this way any trouble through the cook forgetting to order something—as he most always does—will be avoided, and a good check be kept on the amounts of supplies used.

Selection of Men.—In selecting an organization for a location survey, especial care should be taken that every man is strong and vigorous, and capable of doing a good, hard day's work, whether living in camp or not; it is no place for weaklings.

The instrument men have to carry their instruments many miles a day and hustle between points, as often the whole party is waiting while the instrument is being moved up. The leveler and rodman often have to keep up a dog trot all day to keep up with the transit party, and the head chainman sets the pace for the whole outfit in the field, and one slow man may keep the whole party back. At the best many miles have to be tramped during the day over rough country and through fallen brush, often in the wet and in the Winter through snow. Every man should have such an equipment of clothing, especially of heavy boots, that he can go anywhere and through any amount of mud and water when necessary. The writer does not wish to overdraw the picture of the difficulties, and no sane, healthy man who has lived in camp but looks back with longing after he has probably reached a position where he is tied down more or less to his desk in his office, and remembers the joy of living in the open air, and finding a way through a new, undeveloped country, with change of scene every day; and forgets the wet, cold, rainy days and the many discomforts.

CHAPTER IV.

THE PRELIMINARY SURVEY.—FIELD WORK.

Before entering into the details of the work of the preliminary survey proper, it may be advantageous to briefly review the various steps from the inception of the project up to this point, as it is here that a distinct change in the point of view occurs. Up to this point areas have been, or should have been, under consideration, but from this on the problem is narrowed down to a line or lines.

In the beginning, the chief officials of a railroad or the promoters decide that a railroad is desirable or necessary, between certain points and possibly within certain territory. An engineer then examines the territory with a view to its general possibilities, noting the general large features controlling the situation, what the character of the road is likely to be, i. e., what kind of alignment and ruling grades may be expected, the probable cost, etc., and volume of traffic. This report being favorable, it is decided to proceed with the surveys, and one or more locating engineers (according to the length of the line) are placed in the field, assigned to certain sections between main governing points. Each of these locating engineers then thoroughly examines the territory assigned to him, first becoming generally familiar with the broad, general features and the drainage system, and afterwards in detail; this probably leading to the determination of one or more intermediate governing points and certain tentative routes connecting these. It is at this point that the preliminary survey proper should begin, developing by proper instrumental surveys the details of the general routes thus selected.

If all the preliminary work up to this point has been completed by the locating engineer before the party gets into the field, he can personally direct the work of the party on the preliminary survey, but usually speed is an important factor, and

the locating engineer has barely time to make a flying trip over the line, before the party gets into the field, and results are expected, so that an assistant is necessary to actually take charge of the party and run the preliminary lines while the locating engineer continues the reconnaissance for detail in conjunction with, though sufficiently ahead, of the preliminary survey.

As the survey progresses also, new developments open up at times, unforeseen difficulties or opportunities, and the locating engineer should be free to examine these and study their bearing on the whole situation as the survey develops them, and not be tied down to the actual field work of running the preliminary lines.

It has been customary in the past to refer to the preliminary survey as preliminary location, and this, the writer believes, has been responsible for much faulty location, and he would prefer to refer to the work as the preliminary survey, having in mind the idea that the location is not to be made or decided upon until all the factors which determine it are collected and put in such shape that they may be properly balanced and due weight given to each; the preliminary survey being considered solely as a means of collecting and properly arranging this information.

While the preliminary lines will be considered solely as a basis for the development of the country, and as base lines on which the topography may be hung and the map built up, as a matter of practical necessity they should be run as closely as possible to where the final location may be expected to lie; all the good judgment and "eye for country," relied on so much by some of the older locating engineers, are still as necessary as ever, and must be employed in selecting and running the preliminary lines; but they must be supplemented by scientific methods and much hard work.

It is usually customary in anything but the roughest mountain country to take topography for 300 feet on either side of the preliminary lines, thus insuring a map of a strip of country 600 feet wide; and it may be broadly stated that if the preliminary lines are run in such a way that the location falls anywhere within this strip their purpose has been accomplished; as a matter of actual practice, however, it is desirable that the location should fall *well* within the limits of this strip for most of its length, and

if after the map is made it is found that the location for any great length falls near the edge of it, another preliminary line should be run to better control the situation and fill out the topography on the map.

The experienced locator, therefore, while not bothering about his preliminary lines that they shall be a preliminary location, will use sufficient care that they shall be close enough to the final location for the purpose in hand.

The principal difference between the method indicated and that of making a preliminary location is, that in the latter case the endeavor is made to make the location in the field. The preliminary location is run-in some distance on the ground, and if it does not look right the stakes are pulled up and it is changed; and so the party goes along running lines and backing up as the judgment of the engineer behind the transit dictates, and about half the time the party is sitting around waiting, but finally getting a line on which, with a few minor changes, a railroad *may* be built, but which may be far from the *best* line the country affords, either for construction or operation.

It may be, and is, claimed, that by this method, even though time may be lost waiting and backing up, that it does not involve the time and expense necessary to make a topographical map. This may, or may not be so; but, if the topography be taken with a due regard for its use, it is not so, and in any event this method does not allow of that proper, broad, comprehensive view and review of the whole situation which is absolutely necessary for the location of the *best* line the country affords.

In running his first line and attempting to make it a preliminary location, the engineer is more than likely to be influenced by that particular line in all the rest of his work, and his final location will be only an improvement over it, in small details of alignment, and be the line which he first saw, and not the line determined by a study of the whole situation.

Before the location is decided on, all the facts affecting it should be gathered in such shape as to be easily available; the engineer should be thoroughly familiar with the country, and approach the problem with his mind entirely unprejudiced in favor of any details of alignment or grade. Then, with his map before him, he is far more liable to grasp the problem in a broad-

minded way than he is in the field with a big rock or heavy growth of underbrush limiting his view and his grasp of the whole situation.

One writer* recently referred to "the genius . . . . who, disdaining plats, approaches the hillside boldly, line in hand; who takes in at a glance the P. C. and the degree of a curve that will fit the hill comfortably, and at the proper point on that curve sails off on a tangent that will strike the bull's eye two miles away." Nothing could be more dangerous than to encourage the belief that such things are possible even; once in a great while the genius might hit the bull's eye; but nine times out of ten the man in his tent at night with his map and all his facts before him, and by all means the most important, thoroughly familiar with the ground, will be fitting in tangents that will do away with the curves of the "genius," and hit the bull's eye *every* time.

In the opinion of the writer, there is only one place to project the actual location, and that is on a good topographical map.

Provided the topography is generally correct, which it should be to be of any use at all, it is possible to project on it a line which will be the best line the country affords, and if the work is properly done this line can be reproduced on the ground.

In adjusting the line to the topography it can be changed and a profile of each change obtained, fifteen times on the map, while it is being changed once on the ground, and all the problems affected by each change studied.

The author's usual practice on preliminary surveys is, having made the first preliminary reconnaissance and made himself familiar with the general lay of the land, *and especially of the general scheme of drainage,* to keep his reconnaissance for detail about two or three days ahead of the transit party, making liberal use of rough sketches showing the general lay of the country through which he wishes the line run, which sketches are turned over to the assistant. These, with such verbal explanations as may seem necessary, and the general maps, will enable the assistant to identify the various important points of the topography as he reaches them and to run the lines as required.

There will be times, at critical points, when it will be necessary

*Trans. Am. Soc. C. E., Vol. LIV., p. 143.

for the locating engineer to be with the party and project the line from point to point as indicated by the transitman and leveller's notes. All this, however, is a matter of judgment and experience; the locating engineer distributing his time to the best advantage for the general advantageous progress of the work as a whole.

Preliminary lines should be run, topography taken, and a projected location made wherever there seems a reasonable chance of a good line existing, though this should not be interpreted to mean that a topographical map is to be made of the whole country—any surveyor can do that.

The judgment of the locating engineer and his "eye for country" should be trained to select the most suitable routes for the detailed surveys, and he must learn when to depend on his eye—and a hand level—and when to make surveys; at the same time

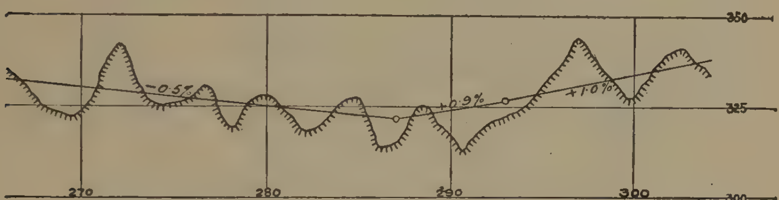


FIG. 15.—PROFILE ON LINE A B FIG. 16.

always actually running a line and projecting a location whenever there is a reasonable probability of a line existing.

The engineer should never be discouraged because a country looks rough, because it has high cliffs, jagged rocks, or is covered with woods or underbrush; very often, in fact more often than not, this kind of country will afford an ideal profile where the smooth, grassy, rounded slopes may prove most expensive.

Figure 15 is a profile on the line A B, Fig. 16, showing that, although the country is rough, it affords a profile on which the cuts and fills nicely balance, with no overhaul, a comparatively inexpensive line; whereas in Fig. 17, page 51, a profile taken in open, rolling country, easy of access, and easy to get over, we have a long, shallow cut, always an undesirable feature, with a long haul, which nearly doubles the cost. It may be noted in regard to Fig. 16 that the country was thickly wooded with badly broken

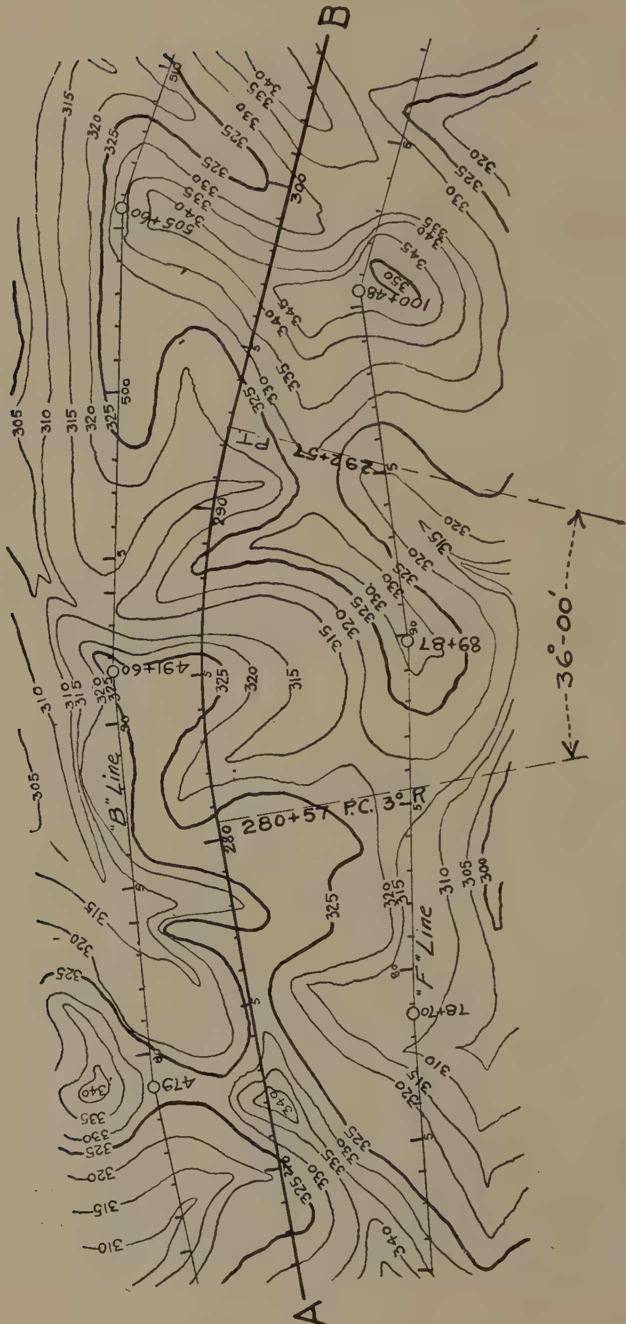

B
A
"B" Line
"F" Line
280+57 P.C. 3° R
292+57 P.T.
36°-00′
505+60
100+48
89+87
491+60
78+70
479

FIG. 16.

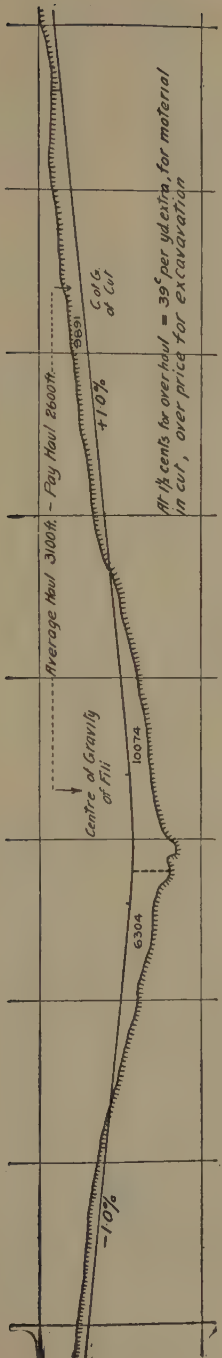


FIG. 17.

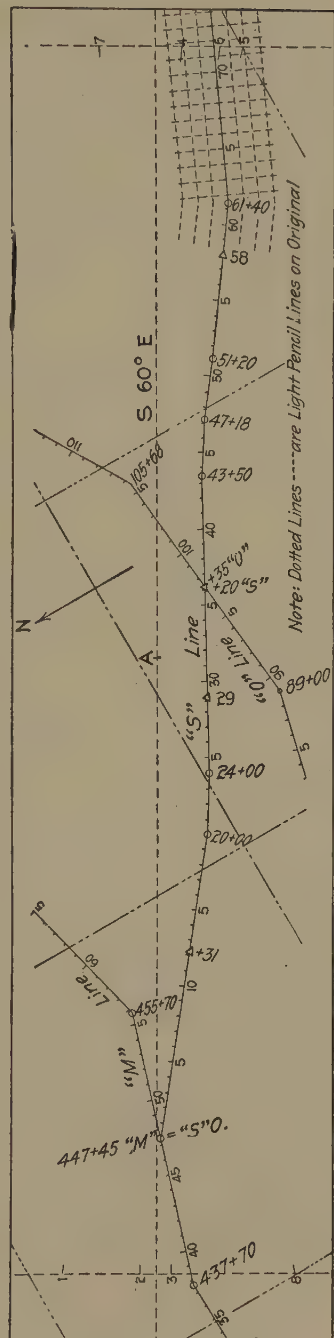


FIG. 20.—(See page 57, also Chap. V., p. 90.)

topography, and two preliminary lines were run, about 600 feet apart, to properly develop it.

The author has made it a practice where he has found a strip of country with the topography badly broken up, no well-defined ridges or valleys, or in other words, no well-defined, regular, drainage system, and thickly wooded, to run two preliminary lines, approximately parallel and about 600 feet apart, getting the topography 300 feet on either side of each line, thus insuring a strip 1,200 feet wide, enough to cover all contingencies.

Perhaps one of the most frequent causes of bad alignment is a more or less rough, broken, thickly wooded country, unless a map is obtained of enough of it to get a good, general broad view on a scale not too large. Figure 16 shows a typical strip of country of this kind which was not only thickly wooded but covered with underbrush.

Apart from the fact that such country can hardly be properly developed otherwise, it will be found that if intelligent methods of taking topography are used, the actual expense incurred in running the two random lines and getting the topography will be less, if anything, than it would be to actually find the line on the ground by backing and filling all over the country.

Ordinarily, the preliminary lines will be run through from one end, developing the country as they go along, one main line being run, and such side lines as may be necessary. In running a grade line, however, it is generally preferable to work down from the summit. The location at the head of the valley is always confined within more or less narrow limits, whereas at its mouth the slopes are not as steep, and there is much more latitude. Where the approach to the summit is comparatively short, however, the line can generally be continued right along; but where a grade line of any length is to be developed, the preliminary can be stopped somewhere near the mouth of the valley, and a new line started from the summit and run back, if it is thought desirable.

In some cases, especially in very difficult country, the line can be run up the valley and the levels carried along, this first line being regarded more as a rather detailed reconnaissance than as the base line for the topography. This line will serve the two-

fold purpose of establishing elevations of certain parts of the approach valley and of carrying the elevations to the summit so that all the levels are referred to the same datum plane.

On lines where a low rate of grade is desired through more or less rough country, one of the first problems to be solved definitely is, what the rate of grade shall be.

For instance, on a line, say, 300 miles in length, it has been tentatively decided to try for a 0.6% grade. Three or four parties may be placed in the field. In this case, the first thing to be determined will be whether a 0.6% line can be obtained throughout the length of the line or not, and if not, what is the least rate of grade that can be obtained..

Each party, therefore, should at first simply push one line through on which the desired rate of grade can be obtained, or show the impossibility of getting it at all. This line need not necessarily be the best line the country affords, but any feasible line, leaving until later the proper development of the country. All of the parties should report to one engineer, who will direct the whole survey and be in close touch with each party as it works along, so that in all probability, before the lines are actually all connected, a decision can be definitely arrived at as to the rate of grade to be used.

It may have been decided to raise the grade, lower it, or keep it as originally proposed, or it may have been found feasible to adopt a certain grade except at one point where a helper or a pusher grade may be necessary. In any event, the further development of the country can then be proceeded with, with the assurance that all the parties are working in accord, and not, as the writer has seen in a similar instance, one party bucking the country and adopting all kinds of expedients to get a 0.6% grade, while on another part of the same route the country was such that a 1.0% was absolutely necessary, and all the work to get the 0.6% was thrown away, as 1.0% was afterwards adopted for the whole line.

The general, broad questions affecting the whole line must be definitely settled before any time is spent working out details.

In the case, as noted above, the first preliminary should be carried through, topography taken, and a projected location made in the same manner as previously outlined and described in de-

tail hereafter in Chapter VI. It is especially necessary that the projection should be made on all preliminary lines where low rates of grade are required, as the shortening of the located line over the preliminary, compensation for curvature, etc., often throws out a line which may seem to be all right from the preliminary profile.

Great care should be taken, however, not to allow this first line to influence the final location. It can probably be stated as axiomatic that the first line selected is never the best, and the problem confronting the locating engineer is to find the better line, which is surely there.

Two rules from the Instructions to Locating Engineers of the Northern Pacific Railroad* may well be remembered by all: (1) "The route of best grades and alignment should always be first projected, working back to the final and most economical route; working in the reverse order usually results in inferior location." (2) "The possibility of obtaining a very good line should not preclude the search for a better one; the greatest and most costly errors occur most frequently in prairie regions."

The Transit Party is usually organized as follows:

Assistant engineer in charge.

Transitman—With transit and transit notebooks; responsible for all instrumental work, gives line, reads and records all angles, and stations of transit points and of land ties where taken.

Head Chainman—Is responsible for the correctness of the chaining, and for the proper selection of instrument points. He will use a round sighting rod, manipulate the front end of the tape, and read all plusses.

Rear Chainman—Will hold the rear end of the tape at the last stake driven, not on it, being careful not to take up the strain of the tape on the stake.

A common fault of rear chainmen is, due generally to laziness, to hold the tape in one hand against the stake, letting the strain of the pull come on the stake, thereby pulling it out of place and lengthening the measurement.

Note—Chainman is really a misnomer; although almost universally used, it is a survival from the days when link chains were used, instead of the steel tape now used to the entire exclusion of the chain.

Stake Marker—Carries a small supply, 20 to 25 stakes, in a canvas bag, marks them with the letter of the line and the number of the station, and drives them.

Rear Flagman—Holds a sight rod, preferably a flat one, on the instrument point next behind that on which the instrument is set up, for a back sight. He records in a note book, kept for the purpose, the numbers of the stations on which he gives back sight in the order in which he holds on them.

*E. H. McHenry, Engineering Rules and Instructions, Northern Pacific Railway.

Axeman—Usually three will be found useful and economical for rapid progress. In heavy timber all are engaged in clearing; where timber is lighter one can assist in driving or carrying stakes; in still more open country, two can help the stake marker; one to drive and the other to carry the stakes.

The team and teamster usually keep as close to the party as the country will admit, replenishing the supply of stakes carried by the stake marker from time to time and furnishing drinking water to the men.

The Assistant Engineer will be in direct charge of all the field work, but will necessarily confine himself almost entirely to directing the work of the transit party. He should usually be ahead with the axeman and head chainman, keeping things moving all the time up ahead. He should be fully informed by the locating engineer of the various features of the country as developed by the reconnaissance so that he may run the lines with intelligence and economy, and so that they will develop the country desired.

The writer's practice has been, as previously noted, to make a series of sketches, showing the topography in sufficient detail to give the assistant a clear idea of where the line is to run. Each evening after the map and profile of the day's work have been platted, they are looked over, and, when necessary, revisions or side lines noted, to be run in the next day. Then with the available maps and the sketches made, the country ahead is discussed, and the points ahead to be developed by the preliminary line explained. While in a sense this leaves little to the assistant but the actual routine work of surveying, he must have had a good experience in this kind of work to properly comprehend the instructions of the locating engineer, and to intelligently run the lines so that they will accomplish the desired results. At times it will be convenient or necessary for the locating engineer to meet the party at various points during the day to see that his instructions have been understood and are being properly carried out, or to see personally that the line is in the right place at critical points.

The assistant should exercise a general supervision over all the members of the transit party, to see that they are doing their work well, although he will spend most of his time either with the head chainman or axeman, or up ahead of them. He should be able to explore the country for a short distance, say four or five hundred feet on either side of the line he is running,

note sizes of streams, rock out-crops and character of same, and anything which will supplement in detail the observations of the locating engineer. While the locating engineer makes his reconnaissance broadly of an area, and in more detail after, of a route, the assistant should make what might perhaps be called a reconnaissance of the line he is running, though always being in touch with the party.

The preliminary lines are usually lettered, beginning with A and going through the alphabet, using all the letters except I and L. I is liable to be mistaken for a numeral, and L is reserved for location stakes. It is desirable, if possible, to have one main line, which is run through, all other lines being side lines. As shown, Fig. 18, 1, 2, 3, 4, 5, 6, 7, is the main line, and has been called the A line, stationing being carried through continuously from zero; the line 2, 8, 9, 4 being the "B" line, its zero being at 2 and its stationing being carried through to 4, where

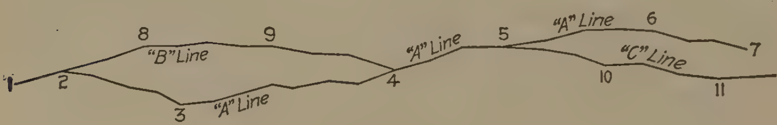


FIG. 18.

an equalization station will be made. At 5 another spur line might be started and called the C line, which it might seem advisable to continue, abandoning the A line.

There is no particular harm in thus continuing the stationing from a secondary point, though it is well to avoid it if possible as it is often convenient to have the stationing continuous on the preliminary to show at a glance the distance from the starting point. The stationing of side lines usually starts at zero, at their point of beginning. It is noted in the note book, as for instance, "A" 743 + 23.87 = "D." 0., and when the "D" line gets back to the main line the equality is noted as "D" 121 + 73.28 = "A" 853 + 29.42 or as the case may be. If the D line crosses or connects with any other side line a proper connection is made, i e. a proper intersection obtained and angle and plus recorded. Care must be taken with all equations, to make the notes perfectly clear, and a sketch of the situation should always be shown on the right-hand page, and the notes properly

cross referenced. That is, as noted in the case above, the "A" line may have been run some distance beyond 743 + 23.87 when the D line is started; on the page on which the D line is started note that A 743 + 23.87 is to be found on page X, or whatever page it may be, and on the right-hand page opposite A 743 + 23.87 note, "equals D. 0.," see page Y, and if in different note books note the number of the book as well as the page. See also Fig. 20, page 51.

The length of line which can be run in a day, of course, varies with the conditions. In the South American forests, the writer has thought himself fortunate when half a mile was cut through the dense underbrush; in the West, with the organization outlined, eight miles have been run, of which about one mile required to be cleared. With three good axemen, and from one-half to two-thirds clearing, which is not too dense, there is no trouble in running two to three miles a day in fairly rough country.

The Transitman.—The form of transit notes usually used is shown (Fig. 19), and these notes, when platted, appear as shown Fig. 20, page 51.

It is not necessary on preliminary lines that the stakes should all be lined in by the transit; as soon as a Hub is set, the axeman and chainman are sent ahead, being lined in by eye by the engineer in charge of the party, until the transitman has arrived at the point, and has his instrument set up; when he (the transitman) can pick up the line from the stakes already driven, or from a foresight which the engineer has probably been using, and line in the rest of the stakes until a point has been reached where it is necessary or advisable to drive another hub. Or the assistant engineer may be up ahead hunting for the line and the axeman can work towards such points as he may select, being lined in by the head chainman. All this, of course, is assuming that the line is not being produced straight ahead, in which case, of course, it is best not to get too far ahead of the hub without being lined in by the instrument. It is usually as well and saves lots of time on preliminary to turn a very small angle rather than attempt to get a straight line for any great distance involving several set ups.

When a hub is to be set, if the line has been produced

Line "S"

Sta.	Dist	Defl	Mag Course	Calc. Course	
⊙ 61+40		11·13 L			
△ 58					
	1020		S 53·00 E	S 53·56 E	6°04' ⑥
⊙ 51+20		2·00 L			
	402		S 52·00 E	S 51·56 E	8°04' ⑤
⊙ 47+18		5·30 R			
	368		S 57·00 E	S 57·26 E	2°34' ④
⊙ 43+50		4·00 R			
△ 36+20					
△ 29					
	1950		S 61·00 E	S 61·26 E	1°26' ③
⊙ 24		3·00 L			
	400		S 58·00 E	S 58·26 E	1°34' ②
⊙ 20		7·00 L			
△ 12+31					
	2000		S 51·30 E	S 51·26 E	8°34' ①
⊙ = 0 "S"		21·15 R			
447+45 M					
			S 72·30 E	S 72·41 E	
⊙ 437+20 "M"	Back sight				
	6140				O.K.

FIG. 19.—FORM OF TRANSIT NOTES FOR PRELIMINARY LINE. (See Fig. 20.)

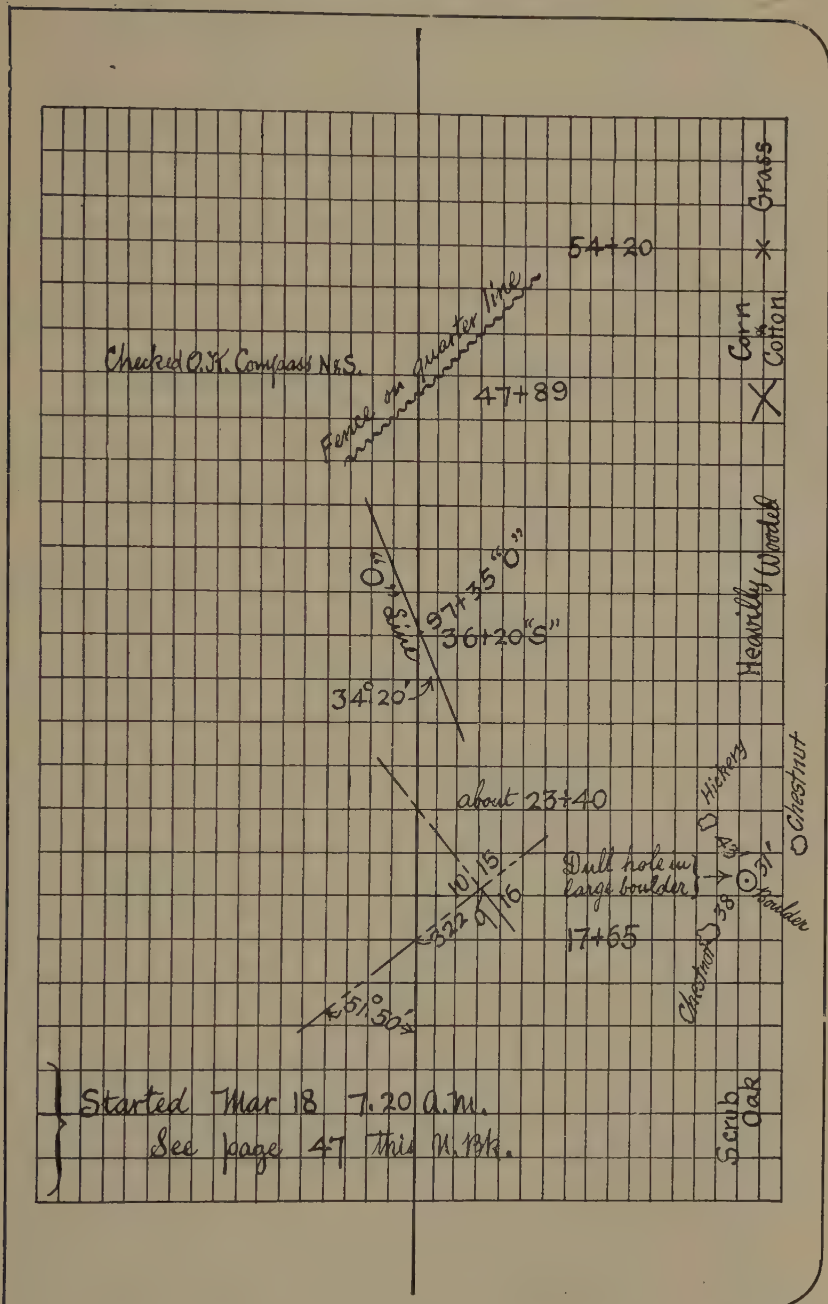


FIG. 19.—FORM OF TRANSIT NOTES FOR PRELIMINARY LINE. (See Fig. 20, page 51.)

straight ahead from the station where the transit is then set up, the head chainman will give the usual signal for a hub by facing the instrument and holding his rod in both hands, horizontally over his head, which signal is answered by the transitman with "all right." The transitman will then sight on his back-sight, turn the telescope in altitude (that is, revolve it on its horizontal axis) and give one point, which is marked on the ground. The transit is then revolved on its vertical axis sighted on the back-sight, the telescope revolved again in altitude and another point given. The hub is then driven midway between these two points. This is usually spoken of as reversing both ways. After the hub is driven, the whole process is repeated and two points obtained (and provided the instrument is in fair adjustment the points will come on the hub), and a tack is set midway between them. This is spoken of variously as double centering, double hubbing, or reversing both ways.

Where an angle has been turned at the instrument point the process is much simpler. When ready to set a hub the head chainman signals the transitman, as before, who gives him careful line, that is, centres his rod; the hub is then driven at this point and a tack driven in the centre of it at once; while the hub is being driven the transitman sets his vernier carefully on zero, sights at his back-sight, and turns the angle carefully to the rod, which is now held carefully and plumb on the tack in the hub; the angle is then read and recorded. As a check, the angle should then be doubled by unclamping the lower motion and without disturbing the vernier, setting again on the back-sight then turning the angle again to the rod; if both operations have been correctly performed the angle will read double what it did at first. As noted in Chapter I., deflection angles are always used on preliminary lines.

This method is the only one the author knows that affords an absolute check that the angle has been *sighted, read* and *recorded* properly. It takes hardly any time to do, and both the transitman and the chief of the party have the satisfaction of knowing that the angles are correct.

Some transitmen, many in fact, after turning the angle, reading and recording it, set the vernier back on zero and see if the cross-hair hits the back-sight; this only checks the first setting

on the back-sight and shows that the instrument has not moved in the meantime; it is no check that the foresight has been properly observed or of what is of the greatest importance that the angle has been read or recorded right. At each angle point before the instrument is moved the bearing of the needle should be observed and recorded, the angle observed added or substracted, as the case may be, from the previous bearing, which result should check (usually within 30 minutes) with the bearing then observed, or if not, the angle and needle carefully re-read. When the transitman is satisfied that he has the angle and bearing properly observed and recorded he signals all right to the head chainman, who may then go ahead, also the back flagman to come up, *and after seeing that both have observed his signals,* goes ahead. The back flagman should record in a note-book the station of each hub he holds on for back-sight, and at the end of each day the transitman will check his notes from these. With these precautions there should never be a mistake in reading or recording an angle or in recording the number of the station of a transit point (hub).

Transitmen should accustom themselves to use the lower motion tangent screw at all times when setting on line and only use the vernier tangent screw when actually setting the plate and turning angles; many mistakes and delays will thus be avoided.

The transitman, in order to do his work intelligently, must be something more than a mere machine who can look through the telescope and see the cross-hairs, and be able to read an angle. He must, in the first place, thoroughly understand his instrument and take care of it, as the party is usually a long way from an instrument maker and any damage to it might, and probably would, result in serious delay to the whole party. It must be kept in close adjustment for colimation, as deflection angles are usually read, involving the reversal of the telescope at each reading. He must have an intelligent appreciation of what is going on up ahead, without its being necessary to send a man back to tell him what to do if some little change in the previously arranged plans is necessary. A good transitman will know what the men up ahead want as well as they do themselves, and he should not wait until the head chainman calls for line, but be ready to give it as soon as it is needed. There ought to be prac-

tically no need of any yelling back and forth between the different members of the party, once they get the swing of the work, neither is an elaborate code of signals (as the writer has seen used) necessary.

In lining in the rod of the head chainman, the transitman will not waste time by exactly centering it for each stake, but will set it within a tenth or two; after line is given the head chainman will see that the chain is straight and level, and that he has the correct distance to the rod, and having it he will then press the point of the rod into the ground, and a stake previously marked will be driven there, the chainman being on his way to the next station while the stake is being driven.

To one unaccustomed to the work this may perhaps appear to involve considerable error in the chaining, but as a matter of actual practice, with good chainmen the error will actually average less than 1 foot in a mile, as the writer has proven time and time again.

The Head Chainman is responsible to a greater degree perhaps than any other one man in the party for the progress of the work, that is to say, the actual physical progress, after the direction of the line has been determined. He must be a hustler from start to finish, and for ten or eleven hours a day, and, at the same time, be accurate; it is no use being careful about the instrumental work and the platting, if the chaining is not well done, and nothing is more annoying than to plat side lines forming traverses and find that they will not close, or to run in curves on location and have them not to check. Chainmen, as a rule, are not college graduates, but are picked up in the country where the survey is carried on, and while they may probably have had some experience, there is no point where the engineer in charge can use his time to better advantage, at the beginning of the survey, than in getting the chainmen to do good work; not necessarily measuring to thousandths but accurately enough for the work to be done. Both chainmen should carry plumbbobs, and use them whenever necessary.

While the assistant will usually select the points where a hub is to be driven, this will often devolve on the head chainman and he should be carefully instructed as to the necessity of selecting these points in such places as are most advantageous

for proper sights with the instrument, both behind and ahead. A man to be a really good head chainman should have had some little experience in using the transit. If he has not, it will be well to endeavor to give him this experience at such times as may be convenient, under the care of the transitman, using the rear chainman at the front end of the chain, and one of the axeman as back flagman or rear chainman. A proper understanding of each other's duties and the difficulties attendant on each, will do a great deal to ensure the mutual respect for, and co-operation with each other, of all the members of the party, which means so much for the success of the surveys. Of course, this will not be misunderstood as advising the continual change of men from one position to another, which is bound to be disastrous. In all these things judgment must be used, and the locating engineer must study his men as well as his other problems.

The head chainman and axeman should avoid calling for line from the transitman any oftener than necessary. If the cutting is heavy and the chainmen have to wait on the axemen the rod should be stuck in the ground at the last stake driven and the axeman trained to keep on line sighting through the rod to the instrument. It should seldom be necessary to call for line except for a stake, and not often then, if the transitman is alive. A most annoying and unnecessary practice is for the head chainman to keep moving his rod every 8 or 10 feet and calling for line, as is also that of allowing the axemen to call to the transitman to give them line; it may be necessary occasionally, but usually the axemen should be able to range themselves in between the head chainman or his rod and the transit.

Before asking for line from the instrumentman, the head chainman should range himself in by eye approximately, by lining over the last stake to the instrument; on curves, by ranging in the last two stakes and allowing for the offset for the degree of curve being run, which he should know; it wastes the time of the whole party and therefore the company's money to have to move the head chainman six or eight feet on to line. Signals should be given in such a manner that it will be understood whether the distance to be moved is a large or small one.

If so far away that the transitman's signals are indistinct, the

head chainman should take a handkerchief or hat, according to whether a light or dark signal can be better seen, and wave it, and the transitman should understand that it is necessary for him to use the handkerchief or hat as the case may be to increase the visibility of his signals. It must be remembered that the transitman can see plainly through the telescope and can probably guess what may be needed.

When a hub is set at a plus, the tape should be pulled ahead until the zero is at the last even station before, so that the plus is read directly without any subtracting; then in going ahead the rear chainman should come up to the hub, holding the plus on the tape at it, the head chainman setting the even station ahead at the 100-ft. mark. In the same way, where it is necessary to "break chain" in ascending or descending a hill,

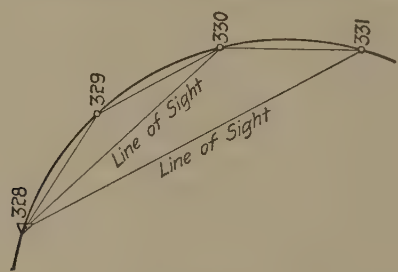


FIG. 21.

that is to say, where the difference in elevation between two stations being more than can be plumbed at once, necessitates measuring the 100-ft. in two or more parts, the chain should be pulled out the full hundred feet, the rear chainman holding his zero at the last stake set; if 33 feet are measured first and a temporary point marked there, then the rear chainman will come up to that point and hold the 33-ft. mark there; if the next point be at 63 feet, that point will be marked and the 63-ft. mark be held on it, and so on to the 100.

Where it is necessary to "break chain" on curves, the head chainman will go out the full length of the chain, then allow a foot or so more and get line from the transit for the station on which he is, nearly; then set his rod there, the rear chainman lining him in from the stake at which he (the rear chainman) is, straight towards the rod. In Fig. 21 the instrument is at 328,

station 330 is set, it is necessary to "break chain" ahead of 330. The chain is pulled ahead and the 100-ft. distance measured approximately and line given carefully for 331, and the rod stuck upright in the ground at that point, which will be very near to 331, then chain directly from 330 towards the rod, breaking the chain where necessary, the rear chainman lining in the head chain by eye, the exact distance will then be found, line is given again, and with the exact distance 331 is set correctly. It would not be correct to get line from the transit for the point at which the chain is broken, as that would involve measuring around the arc of the circle, whereas all railroad curves in American practice are calculated on a basis of 100-ft. chords. A moment's thought should make this perfectly clear, but the writer has very often found it necessary to explain the matter thus fully and even more so to chainmen to make them understand why it should be done.

The fact that circular curves on railroads are designated in this way involves a slight error where points are set between the full stations, but this seldom occurs except at the beginning and end, and if necessary, allowance can be made for this.

The Rear Chainman should either hold the end of the tape while it is being pulled along by the head chainman or be a little in advance of the rear end to see that it is not pulled beyond the station, and so make it necessary for the head chainman to come back 15 or 20 feet. He must not hang on to the tape or be dragged by it and he must look out and free it if it gets caught in the rocks or bushes. He must check the numbering on the stakes and if in doubt go back to the last station and be absolutely sure there is no mistake before he goes ahead. When the rear chainman arrives at the stake last driven, he should see that it is correctly marked, then call out the number to the head chainman, who will see that the number on the stake the stake-marker has ready to drive, is correct, thus affording a double check on the numbering. He must be careful to keep off line, as the transitman has to see by him to line in the head chainman; he must always keep on the outside of curves on location. The rear chainman must always do up the tape when the day's work is completed, and take care of it. He should see that the tape does not touch the tripod of the instrument as it is pulled by.

Stakes should be made usually, in camp by the axemen, assisted by the rodmen, chainmen, etc., if necessary; any ordinarily good wood will do on preliminary; oak or chestnut should be obtained if possible on location, and for location every stake should be full-sized, 18 inches long and not less than 2 inches wide at the top, blazed smooth on both sides, one side for the number, the other for the cut or fill to be marked later.

Once in awhile it may be necessary to make stakes on the line, but this should be avoided as much as possible, as it delays the work. In open country it may be necessary to buy lumber, in which case laths are good for preliminary and hard pine for location. Hubs should be about 2 inches to 3 inches in diameter or 2 inches by 2 inches square timber.

The Axemen should be trained to keep on line and to cut only what is actually necessary. If one can be obtained to fill the position, he should be made head axeman; but care must be taken to select a man who will not abuse his authority, rather than

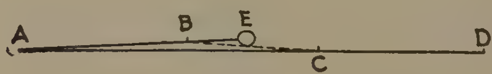


FIG. 22.

this all should be equal. Some men, although they may be excellent as wood cutters, fail as axemen on a survey, from their inability to comprehend what is wanted, spending a large part of their time clearing what is not needed and therefore delaying the work. With green men time and pains must be taken to explain what is wanted and why, and men of ordinary intelligence should soon learn; if they do not others should be substituted. Something more than mere ability to fell a tree properly is necessary.

With proper care on preliminary lines much clearing may be avoided. Often in thick timber the line will hit a large tree which had not been seen when the direction of that particular line was given, in which case it will seldom do any particular harm to shift the line to pass the tree without changing all the stakes between the instrument and that point as, see Fig. 22.

The line has been run from A to B, when the tree E is found in the way. The direction is changed to A-D to just clear

the tree and the line for the next station ahead of B is given at C; the error in chaining will be due to the difference between the length of AB + BC and AC, which will be so small as to be negligible if the angle BAC is very small, as it will be for any ordinary tree at some distance say 400 or 500 feet from the instrument. If, however, an obstacle is encountered which will make the difference appreciable, the chainman can go back to A, or some other means be taken of getting around it which will avoid cutting it down. On all of this work in running the preliminary lines, the scale of the map must be remembered, and the fact that the only error in having a stake out of line will be to affect the location of the contours that much. If this occurs on a steep side hill it might mean considerable; in ordinary country no appreciable difference could be found on a map at 400 feet to the inch.

To realize fully how little difference such a change will make, a case of this kind should be platted on a scale say 200 feet to the inch. Let a tree, 4 ft. in diameter, be drawn 500 ft. from the instrument point. Then draw a line to just clear the tree, which will, if the line is headed directly for the centre of it, necessitate moving the line 2 feet one way or the other at the tree. Then from station 4 on the original line draw a line to station 5 on the new line. It will be found that at 200 ft. to the inch these lines will scarcely vary from a single straight line. Judgment and experience must be used in all these cases, of course, and care must be taken to avoid errors which affect the results, at the same time avoiding work which will increase the cost of the survey without increasing its efficiency.

It is in trying to impress his readers with the necessity of using judgment at every step that the author finds the most difficulty, as he especially wishes to avoid even the appearance of advocating inaccurate work; at the same time he wishes to show where time and money may be saved by avoiding the expense of unnecessary refinement.

The assistant in charge of the party must be alert all the time, to keep the men moving. There should seldom be any necessity of their standing around waiting, on preliminary lines. He can choose his lines to avoid trees and underbrush knowing that the topography will cover a wide strip on either side of his

line; at the same time the closer the preliminary is to the final location the easier it will be to run in this latter. As soon as a point is reached where it is desired to change the direction of the line, the axemen should be sent ahead on the new direction whilst the hub is being set, and then the chainmen kept going until the transit comes up. Or, if it is necessary for the assistant to go ahead, the head chainman can keep the axeman on the required line towards him.

In the West, or wherever the land has been laid out in sections, etc., by the Public Lands Surveys, accurate ties to section corners should be obtained by the transit party on the preliminary, the topographer taking care of smaller fences, and the location of buildings, etc.

In more thickly settled parts of the country other methods of obtaining the artificial topography will be used as noted more particularly in Chapter VII.

The Topographer.—In some respects the most important position in the party is that of topographer, and oftentimes the most difficult to fill. Quoting from Mr. S. Whinery*: "He must possess a keen eye and a good judgment for locality, distance and elevation. If he depends too much on the tape-line and the hand-level, and lacks discrimination as to relative importance of topographical features, he will neither be able to keep up with the party, nor do his work satisfactorily. Particularly must be have the ability, natural or acquired from experience, to judge of the relative importance of the topography he sketches. He must know at a glance, from the general lay of the country, that the final location will hug this hillside closely, and its topography therefore must be taken accurately, while that other will not be touched, and therefore may be sketched with less care. A poor topographer is somewhat worse than useless, while a superior one is cheap at almost any salary."

Little need be added to this estimate of the topographer, but opinions of engineers as to the value of topography, methods of taking it, and necessary accuracy, vary perhaps more than as to any one detail, this being strikingly brought out in the discussion of the writer's paper.

*Trans. Am. Soc. C. E., Vol. LIV., p. 144.

Many engineers have objected to topographical work on railroad location on account of the expense necessary for accurate topography, but this latter and the expense incident to it is entirely unnecessary if the locating engineer in charge of the party knows how to place his projections on the ground so as to equalize any slight errors made. The difference between theory and experience, here, is that theory would require an absolutely accurate preliminary and topography, while experience shows that neither is essential if proper methods are adopted in getting the final line on the ground.

The author has preferred, personally, to work entirely alone in getting topography, pacing out the distances and using a hand-level with no other support than the height of the eye, and he has proven, at least to his own satisfaction, that perfectly satisfactory work may be done in this manner. That is, that the topography may be taken in this way more rapidly and economically than in any other; economically in the full sense of the word, that sufficient is taken, sufficiently accurately for the purpose in hand (which it will always be remembered is getting the best line that the country affords), and at the least cost.

Usually, a tapeman is assigned to the topographer, and he may have besides a cloth-tape, to be used on any steep slopes which demand it, a light rod about 2-in. x ¾-in. x 12 ft., marked every half foot, which will be found useful in dense underbrush and on the downhill side. The material for such a rod can be obtained at any lumber mill, and it can be easily fixed up in camp. Both the topographer and his tapeman should be capable of pacing distances up to 300 ft. in anything but the roughest country with an error of less than 10 ft., which is close enough on any scale 200 ft. to the inch or smaller, and the tape should not be used except for the steepest slopes or rocky bluffs. Where very steep slopes are encountered it may often be found economical to run two transit lines, one near the upper and one near the lower limits of the topography required, thus avoiding reaching out over 150 ft. or so from each line.

The author has seen a party of as many as five men taking topography to be platted at 200 ft. to the inch, two with the tape, one with a level-rod, one with a hand-level on a 5-ft. stick, and one to keep the notes. This outfit rarely covered more than

half a mile a day in little more than rolling country, in which a good topographer alone, or with one assistant, should cover a mile and a half. They got their topography accurately, although there was a doubt of that even, but the point is, that such accuracy was thrown away, and the expense incident to it unnecessary. In the particular case referred to, accuracy was carried to the extent of running out to the limits with the hand-level held on the 5-ft. stick, with readings on a level-rod, and then checking back to the center. This, of course, is an extreme case, which an experienced locator would hardly consider probable, but it is cases of this nature which have discredited the taking of topography on account of the expense and time involved.

Levels can be carried a distance of 300 ft. from the line with the hand-level held at the height of the eye, sighting only at points on the ground with an error of less than, say, roughly, 1 ft. in 25 ft. of vertical height. This the writer considers a much larger error than would actually occur in practice, though an error as large as this would not affect the location of the line in any way. There are too many factors entering into the question of the final location to make a few errors in the location of the contours at all vital.

If the preliminary lines have been run with a due regard to their use, the projected location will average, say, not over 150 ft. from them, probably less; supposing as a very extreme case that the location of the contours at that distance out varied 5 ft. from their proper position at places, it will be readily seen that, using a scale of 400 ft. to the inch, that this cannot be platted, and even at 200 ft. to the inch would have very little, practically no, effect on the projection of the location. (See also page 126.)

The author would again wish to emphasize the point that he does not believe in or advocate slipshod or inaccurate work, but wishes to point out that by using the methods advocated, viz., the hand-level at the height of the eye, with little more than intelligence and common sense, and possibly a light rod with the tape at critical points, results can be obtained which are sufficiently accurate for the required purpose and at a minimum expense.

The author believes that a proper appreciation of points of this nature, which will result in a true economy, will do more than anything else to enable those who do properly appreciate them

to overcome the disposition to pay engineers small salaries, of which complaint is often made, than any amount of letters to the engineering periodicals. Again, instead of complaining as is often the case, that men and money are not furnished in sufficient quantities to make proper surveys, a proper knowledge of what is absolutely necessary should be brought to bear on this work, and only such work done as is absolutely necessary to get results. Much more might then be accomplished than where time and money are wasted on unnecessary work.

It is always best, when possible, to have money, men, and equipment of sufficient quantity and quality; but engineers, more than any others, must face facts (which are, that these are not always to be had), and not expect always ideal conditions.

Probably the most satisfactory and most generally used method of taking contours is to locate the even 5-ft. contours on the ground. If the separate sheet method is used, the preliminary line is first platted on it and inked in, each station being marked, some sort of portable drawing board is arranged and the contours platted directly on the map in the field. The advocates of this method claim that this is cheaper, but as a matter of fact, it rarely is, as it takes three men to work it properly; one with the map and drawing board, and two locating the contours, and the part of the map you want to use in the office is generally in the field or somewhere else.

The author prefers a note book, ruled in squares, similar to ordinary cross-section paper, the larger squares defined by the heavy lines being used as 100-ft. each, and the smaller ones as 10-ft. A sample page of one of these books is shown, Fig. 23.

The elevations and stations are copied from the level notes the evening previous along the margins of the book, and as the contours are located in the field, at each station, or as often as necessary, they are marked and their position in the intervening space between stations sketched in, thus making a drawing in the note book on a scale of about 80 ft. or 100 ft. to the inch.

The draughtsman will usually be easily able to transfer to the map and ink in, in two or three hours, all the contours, that one good topographer can take in the field in a whole day. A good topographer will ordinarily take about two-thirds as much topography as the transit party can run lines, so that usually when it

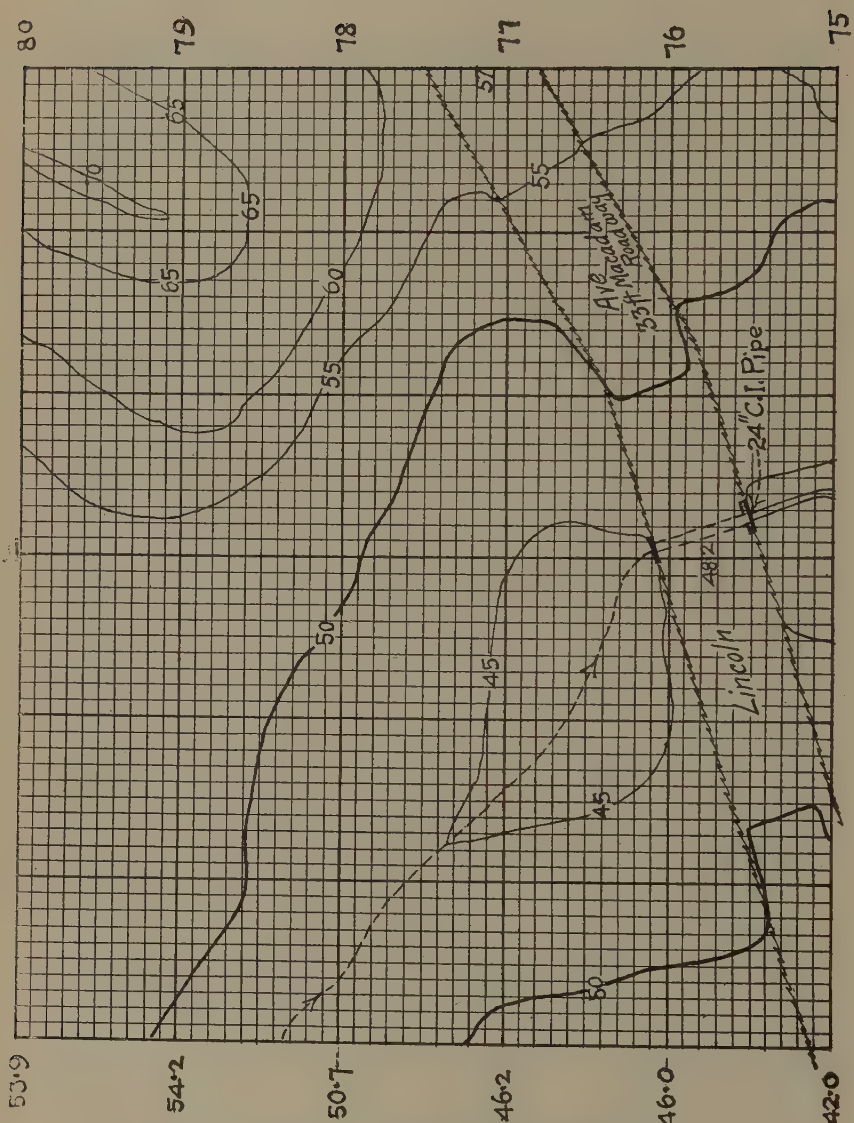


FIG. 23.—TYPICAL PAGES TOPOGRAPHY NOTE BOOK.

FIG. 23.—TYPICAL PAGES TOPOGRAPHY NOTE BOOK.

becomes necessary to move camp the topographer is a day or two behind; then the whole party can be broken up into topography parties and the work cleaned up, or nearly so, in one day, or arrangements may be made to keep the topographer in the field on moving days.

The transit party will, of course, run some side lines occasionally on which topography will not be needed, and this will often give the topographer a chance to catch up.

The Leveller.—On preliminary lines the leveller is expected to run an accurate line of levels over the lines run by the transit party, getting the elevations of the ground at every station and at as many intermediate points as may be necessary to give a profile of the ground, consideration being given to the fact that the profile is to be platted on a scale of 400 ft. to the inch horizontal, and 20 ft. to the inch vertical.* At this scale elevations may be platted to the nearest tenth of a foot, and horizontal distances to within about 5 ft. Where possible the levels are started from some bench mark, the elevation of which in relation to some known datum plane is known; but frequently this cannot be done, in which case a bench mark is established near the beginning of the line, and an elevation assumed, so that at no part of the line will the elevation of the ground fall below the zero of its datum plane.

Readings on bench marks and turning points should be taken to the nearest thousandth of a foot, and bench marks established at least not farther apart than every fifty stations, or one mile; at all stream crossings and overflowed bottom lands care should be taken to get elevations of any marks or indications of high water.

Levels should be taken for 500 feet on either side of the line on all streets and highways crossed, and for one mile on either side on railroads. The form of level notes is shown, Fig. 24.

Great care should be taken to accurately locate and describe all bench marks and turning points. When a survey is started from a certain bench, state exactly from whence the information as to its elevation was obtained. When a bench is checked on, besides its description, note carefully its original elevation and the book

NOTE.—Plate "A" paper (Plate "B" used sometimes for mountain location has a vertical scale of 30 ft. to the inch.)

and the page where it was originally established, or where it is referred to, and note in the original book that in book *x*, page *y*, is to be found a check, elevation *000.00*.

The writer would wish to emphasize the above, as he has found particular difficulty in getting levellers to thus properly reference their notes, and he knows from experience that it is very essential.

The method of procedure in reading the rod on bench marks and turning points should *always* be as follows:

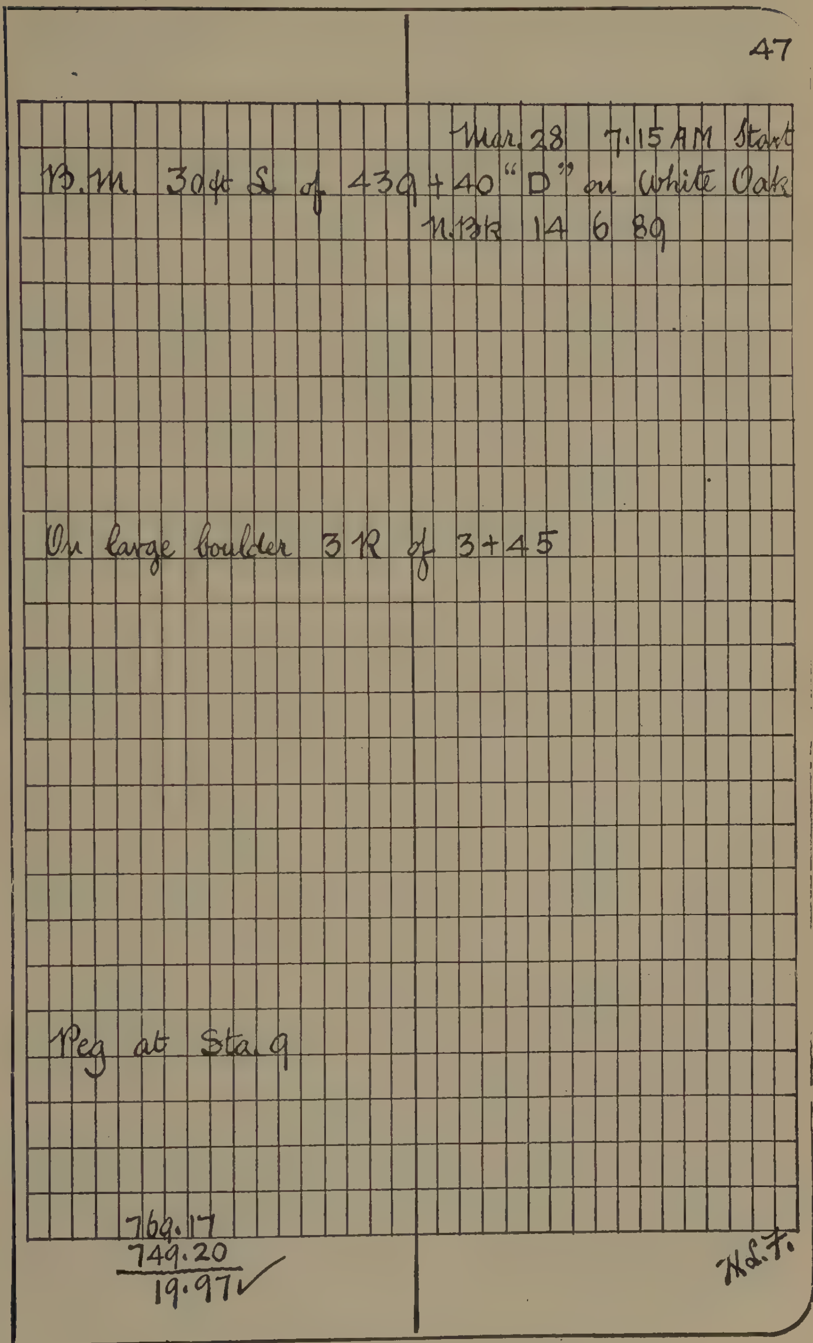
The rodman will hold the rod on the bench mark, keeping it plumb; the leveller sighting at it through the level will then read it as carefully as possible, mentally noting the reading or recording it temporarily in his notebook on the right-hand page; he will not communicate this reading to the rodman in any way. He will then signal the rodman to raise or lower the target and set it (the target) as closely as possible with the instrument; when set, the rodman will read the rod to the nearest thousandth and call the reading to the leveller, which reading should agree with his own observation as far as the nearest hundredth; if it does not, the whole process should be repeated. This gives a check that the rod has been properly read by the rodman; at least, within a few thousandths. Mistakes are more often made in reading the feet or tenths wrong than in the thousandths. The reading, when satisfactory, is recorded by the leveller and rodman, and the elevation of the height of instrument or of the bench mark or turning point, as the case may be, is then worked out independently by both. Neither should announce his result until he is sure the other has finished his computation; the notes are then compared, and if they agree the point is passed. The rodman should keep the elevations of all bench marks and turning points and their descriptions in a regular level book, but need not record the elevations of any intermediate stations. When an old bench mark is used or checked on, the rodman should look up its elevation in his own book, independently of the leveller, and the cross reference should be immediately noted in both places by the leveller. By a strict attention to this method of procedure errors other than those of the instrument can be practically eliminated.

When setting the target on the rod, after the target has been set as closely as possible, it should be clamped and the rod swung

Line "S"

Sta.	B.S.	F.S.	H.I.	Rod	Elev.
B.M.					749.20
	10.24		759.44		
S 0				6.2	53.2
1				8.3	51.1
+35				10.4	49.0
+40				10.8	48.6
2				8.4	51.0
3				4.1	55.3
T.P.		1.06			755.38
	7.48		765.86		
4				5.4	60.5
+65				1.1	64.8
5				3.2	62.7
6				5.1	60.8
+30				7.8	58.1
+60				10.1	55.8
7				9.3	56.6
8				8.1	57.8
9				6.2	59.7
T.P.		6.23			
	9.54		769.17		
10				6.4	62.8
				4.6	64.6
				3.2	66.0
	27.26 7.29 19.97	7.29			

FIG. 24.—FORM OF LEVEL NOTES.


47

Mar. 28 7.15 AM Start

B.M. 30 ft L of 439+40 "D" on White Oak

N.Bk 14 6 89

On large boulder 3 R of 3+45

Peg at Sta. 9

769.17
749.20
19.97 ✓

H.L.F.

FIG. 24.—FORM OF LEVEL NOTES.

gently to and fro in the plane of the instrument; if the target rises above the cross hair the rod was not held plumb; if the target on swinging falls below and just comes up to the hair the rod has been held vertically.

Signals should be made with some system, a whole arm motion indicating 1 ft., a motion of the hand from the wrist one-tenth, and of the finger one hundredth.

The author at one time had a leveller and rodman, neither of whom had very much education of any kind, but who ran levels on various lines for nearly a year without making a single error except such as were due to the instrument. Nothing is more annoying or liable to cause trouble than to find errors in the levels, and no precautions should be omitted to eliminate them.

The procedure described above may possibly seem long to the reader who has never tried it, but the writer knows from actual experience that it takes no more time than any other method of readings on turning points, while ensuring accuracy by checking each step. It is often said that no man can get along if he has much work on hand without making mistakes; but while this is true, it is also true that engineers, at least, can check every step they take and discover their errors. It is no crime to make a mistake, but do not let any one but yourself find it out, and find it yourself before it does any damage.

While the leveller should be accurate, he must also be rapid and keep well up with the transit party, especially where a grade line is being run; if he cannot keep up by walking, he and the rodman must run. This generally only applies to the preliminary, as on location the accuracy with which the work has to be done by the transit party and the curves to be run prohibit rapid work, and the leveller always has time to spare.

On preliminary lines a good leveller should have no difficulty in running three or four miles over quite rough country and up to seven miles in open, rolling prairie country.

At noon and at night the computations should be checked by adding all the foresights and backsights, thus getting the difference in elevation between the first and last bench mark. A good leveller will calculate all his elevations as he takes his notes and not leave them until the end of the day. The rodman should check the elevations of the intermediate stations after they

have been calculated by the leveller, initialing each page to show that this has been done. The profile obtained should be platted each evening immediately after supper, so as to be available for the use of the locating engineer as soon as possible.

The profile should always be platted in the same direction as the line lays on the map when looked at right side up. That is, if the stationing on the map runs from left to right, the profile will be platted with the stationing running the same way; if the map runs from right to left, the stations on the profile will also run from right to left.

On location the levels and the elevations of all intermediate points should be taken more carefully than on the preliminary surveys; care should be taken that the lengths of sight of backsights and foresights at each set up should be equal, thus eliminating any error of adjustment of the instrument. The rod should also always be held exactly at the stake and on the same side as the number, so that this point can be used in cross-sectioning later.

At the sites of all bridges or viaducts, extra care by measuring in the plusses and getting the smaller inequalities should be taken, so that the profile at these points can be platted at any desirable large scale and show all the inequalities of the ground.

At any streets which may be crossed, levels should be taken at each side at the property line, at each curb and gutter and at the center, and plusses measured to all.

Ordinarily, plusses to inequalities of the ground should be *paced*, but plusses to streams on location, as well as to any point of importance, must be measured, and care taken to take all measurements on line.

Note Books.—All note books should be numbered before being issued. The writer usually reserves certain numbers, say from 1 to 20, for transit books; 21 to 50 for level books, and 51 and above for topography books. When starting a survey, if there are on hand say half a dozen transit books and one dozen each of level and topography books, these are all numbered, at once, before the survey is started, and when new books are given out they are issued in regular order. They should be paged through to the end by the men using them, immediately on being issued and before they are taken into the field.

This should be strictly insisted on, as it helps considerably in getting the notes properly cross-referenced. If the books are not numbered and paged before being issued, the referencing is naturally left until they are, and then is generally neglected altogether, causing much trouble and loss of time when some fact has to be investigated, necessitating referring back through the notes. It is sometimes desirable to leave the outside of the books free from any marks until finally placed in the company's files, in which case the number of the book for use on the survey can be placed on the inside of the cover. If the outside is available on the survey, the number should be marked plainly on the front cover and on the back, at the top, care being taken to make all the numbers uniform and in the same position on each book.

The date of beginning and ending each day's work should be entered in the note book, *in the field, each day,* and not be left until afterwards. On the fly leaf of each note book a title should be lettered, or very plainly written, somewhat as follows:

C., O. & G. R. R.,
Preliminary Levels,
Chandler to Okmulgee.

J. Jenkins, Levelman;
P. Lucas, Loc. Engr.

The first page should be left blank for table of contents, which should be kept up-to-date, and may be arranged somewhat as follows:

No notes of any kind should ever be erased or destroyed, or pages torn out of note books for any reason. If the line is backed up and part of it abandoned, the notes should simply be crossed out by drawing two diagonal lines across the page and writing the word "Abandoned" across it, in such a manner, however, that the notes will still be legible.

Office copies should be made each evening of the transit notes on both preliminary and located lines, and of the location levels. These notes should be an exact reproduction of the notes in the field book, including all abandoned lines, etc.

The author would wish to insist particularly on the necessity of following closely these remarks on notes and note books. He

has himself arrived at the point of insisting on this on all work with which he is connected, only through having found from actual experience that it pays, and that it not only takes time and therefore money to decipher or hunt up notes that are not properly taken, or perhaps not properly referenced, but that slovenly notes are a pretty sure indication of slovenly work all around. Care should be taken, on all surveys, to see that all men keep careful, accurate notes in a neat manner. It should never be taken for granted by the chief of the party that the men ought to know how to keep notes, but he should have some well tried and proven system of his own, and insist that his methods be followed by all the men, and see himself that they do it.

General Remarks.—While it may appear to many readers that much minute detail has been entered into, the author would like to emphasize the fact that the methods advocated are the result of experience and not theory. The author has been connected with much bad location (perhaps, fortunately for him), and believes he knows nearly all the many different ways such surveys should not be conducted. If the methods advocated are carefully followed there never need be any errors of moment made, such as reading an angle wrong or recording it to the right instead of to the left, or making feet mistakes in the levels, any one of which might cause serious trouble or inconvenience, to say nothing of perhaps vitally affecting the location.

Locating engineers are often sent out with a party in which no two men have ever worked together before, and often in order to make a showing they push the work at the start, regardless of methods, instead of breaking in the men to work together and in a proper manner from the beginning.

The author once started a line with a party, of which not only was it the case that the men were all strangers to one another and himself, but not a single man had ever had any railroad experience, to say nothing of location; he was himself a stranger to the officials and was naturally anxious to make a showing. After a week's work, with everybody going as they pleased, he realized that he was not living up to what he knew to be the proper method, and that things were not going as they should. He therefore pulled up short, took the party in hand, and, making the amount of work accomplished a secondary consideration,

insisted on each man doing his work as it ought to be done. The progress of the work was delayed perhaps two or three days then, but he knows that this time was more than regained in the end, besides assuring his own peace of mind that he was getting results which he could rely on.

There is no reason why both the field and office work of a location survey should not be carried on without a single error of the kind that affects the results; no great refinement of work is ordinarily necessary, but it should be generally absolutely accurate within the limit of error allowable for the results required.

The author has always made it a point to explain to all the men, as far as was consistent, what they were doing and why they were doing it; especially so to any who took an interest in the work, thus stimulating this interest and conducing to the benefit of all concerned. This he considers especially necessary in camp. where there are few if any interests outside of the work, and where it is especially incumbent on the chief of the party to keep personally in touch with the men, studying them and their environment. No survey can be carried to a successful conclusion by one man alone, no matter how much he knows; he must have the loyal and steady co-operation of all the men under him, working intelligently and all together for the final result, and the locating engineer's position should be more that of directing the efforts of all his men to one common goal than trying to do it all himself. If in camp he must look out for the physical welfare of the men just as carefully as he does that their work is properly done. There will always be certain work which the chief of the party must do himself, but to get the best results this should be confined to such work as he alone can do, because of his greater training and experience, leaving the rest to the other members of the party, who should be properly trained each to do his share.

CHAPTER V.

MAPS AND OFFICE WORK.

The draughtsman must be rapid, accurate and neat. He need not necessarily be a fine letterer, or capable of doing fancy work, but must be able to plat the preliminary lines accurately and the topography as fast as it is taken. To keep up he must be capable of getting through a fairly large quantity of work each day and be able to letter plainly and neatly at least, be a quick and accurate calculator (addition, subtraction, multiplication and division), and be capable of making the estimates under the direction of the locating engineer.

The following maps should be made in the field and kept up to date:

5,000-*ft. Map*—Map on scale of 5,000 ft. to the inch, showing the whole length of the line and the principal features of the adjacent country. Fig. 25.

Detail Map.—This is the working map, and is usually drawn to a scale of 400 ft. to the inch, except where the topography, natural or artificial, requires a larger scale in order to show necessary details. Fig. 26.

Profiles of Preliminary Lines—Platted by the leveller.

Profiles of Projected Locations, with Tracings and Estimates of Quantities.

Profile of Final Location, with Tracing and Estimate. Fig. 27.

The 5,000-Ft. Map.—The map on the 5,000-ft. to the inch scale should be compiled from the best available maps of the country as soon as possible after the survey is started or even before. Such a map, when first compiled, would probably have little more information on it than is shown, Fig. 28.

After the first reconnaissance the notes then taken are added, as shown (Fig. 29). Then as the work progresses, the preliminary lines are platted, and any information which the surveys develop, and finally the projected location. Figure 30.

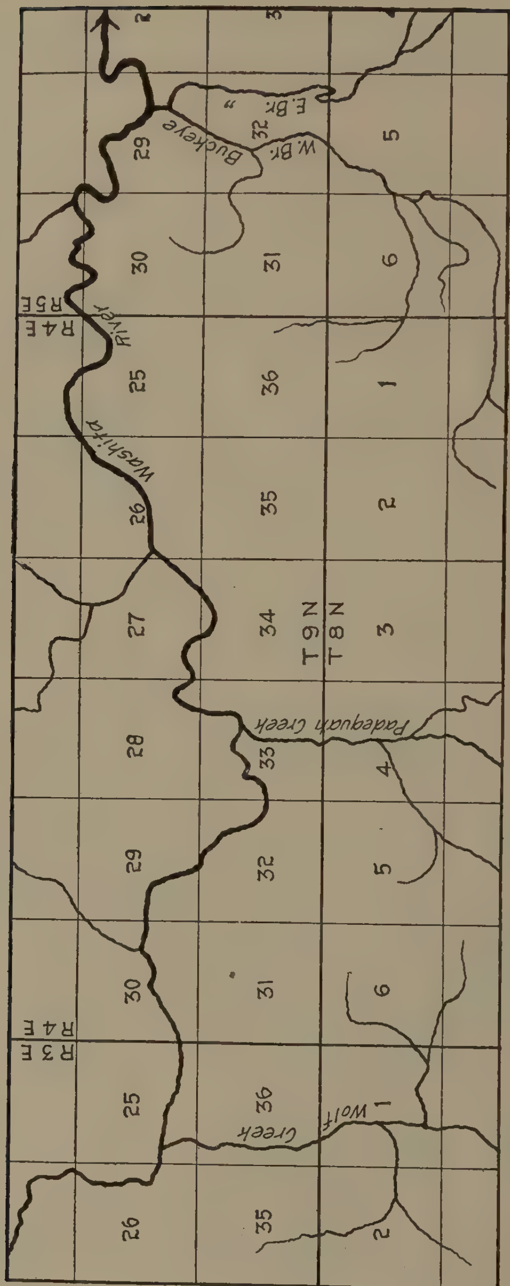


FIG. 28.—ORIGINAL MAP SHOWING ONLY SECTION LINES AND MAIN DRAINAGE USED AS BASIS FOR 5,000-FT. MAP. (See also Figs. 29 and 30.)

FIG. 29.—5,000-FT. MAP. SAME AS FIG. 28, WITH ADDITION OF RECONNAISSANCE NOTES.

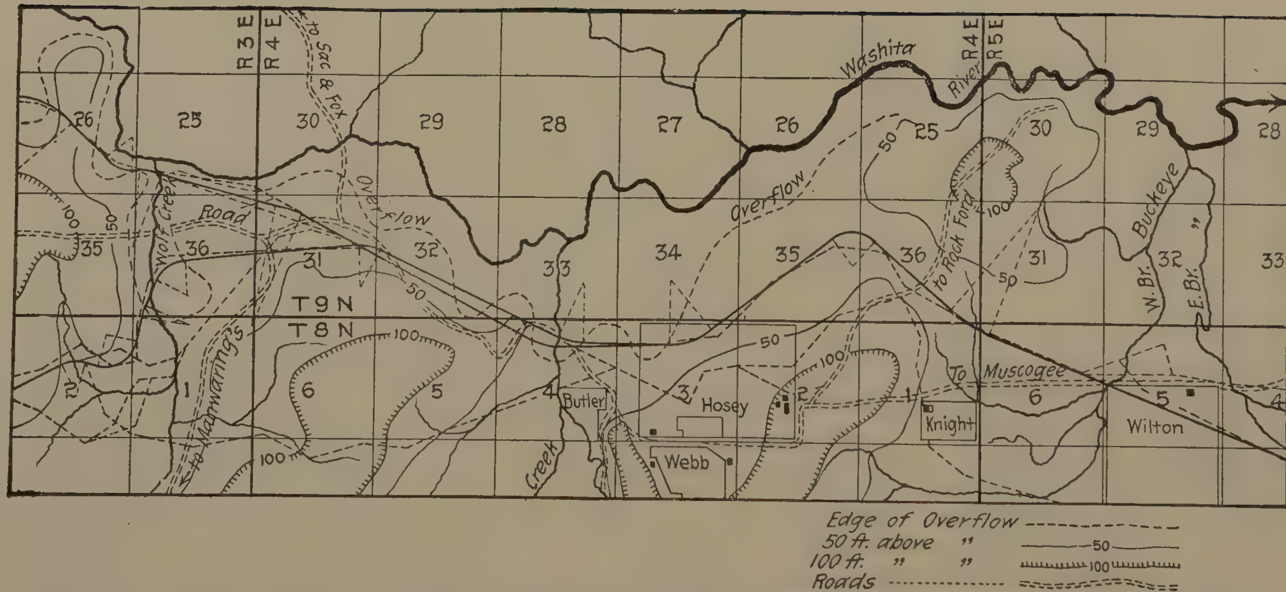


FIG. 30.—5,000-FT. MAP. SAME AS FIG. 29, WITH ADDITION OF INFORMATION DEVELOPED BY SURVEYS, PRELIMINARY LINES (DOTTED) AND PROJECTED LOCATION. (See also Fig. 25.)

NOTE.—Various colored inks were used on original, which made the apparent confusion of the lines less noticeable.

Too much detail should not be included, only the broad general features of the country, main roads, railroads, etc.

This 5,000-ft. map and profile is very essential to a broad, comprehensive study of the line as a whole; it shows very readily whether or not a good general direction is being maintained; the relation of two or more lines to each other, and the general relation of the line to the surrounding country. Such a map, with the omission of the preliminary lines, is of considerable aid to contractors in computing the haul of construction material and for other uses; it is also generally sufficient to accompany such reports as are made to the higher officials; in fact, is usually preferred, as it gives them a more comprehensive idea of the line than a more detailed map. (Fig. 25.)

The 5,000-ft. map is another aid to what the writer considers the most important feature of the methods advocated, *i. e.,* the ability to study, and necessity of studying, the line as a whole, in contrast to methods which usually result in the concentration of the engineer's thought and effort on only a small portion of the line at a time.

A tracing of the 5,000-ft. map may be made as soon as it is compiled, and at the beginning of the survey, and then sent to headquarters. Each week a small tracing, showing the additions made to the map in the field during that week (the preliminary lines run, projected locations made, etc.), can accompany the weekly report, and the information thus shown be transferred to the whole tracing at headquarters, thus keeping a record there for easy reference of the exact status of the work and keeping the chief engineer in close touch with what is being done.

The Detail Map.—This map should usually be made on a scale of 400 ft. to the inch in anything but the roughest mountain country or for lines near large cities, where land is valuable and subdivided into small areas and lots. Too large a scale is apt to result in poor alignment from the endeavor to fit the line too closely to the topography. Where the natural topography, as shown by the contours, is the controlling feature of the location, as it usually is, the scale of the map will be governed by the ability to show 5-ft. contours clearly. This will not mean that if a steep slope is occasionally encountered the whole map should be made large enough to show it, but that the scale will usually only be

made larger than 400 ft. to the inch when, as in really mountainous country the general features require it continuously.

Whilst probably there is no argument from a theoretical standpoint against using odd scales, as 50, 60 or 300 ft. to the inch, as a matter of practice it is better to use the even scales 100, 200 and 400, on which distances can readily be scaled in an emergency with a 2-ft. rule, and which are those most commonly in use, and to which engineers are more accustomed.

A word of caution in regard to good alignment may be necessary. It is often necessary to sacrifice alignment to grades, and the necessity of this must always be borne in mind; at the same time bad alignment with no compensation in lighter grades or less cost of construction is often the result of a cramped view of the situation. A broad comprehensive view will often show where the alignment may be bettered with as good or better grades, and no greater, often less, cost of construction.

The question of separate sheets or a rolled map for the working map is one which has been often discussed, but the writer is absolutely in favor of the rolled map. One of the essentials of a successful location is the continuous study of the problem both on the ground and on the map, working back and forth on various projected locations until the locating engineer is thoroughly soaked and steeped in the details of the country.

With his map on a roll he gets a comprehensive view of the whole situation, and he rolls it back and forth with no effort and with nothing to detract his attention from the study of the situation; with the separate sheet method, there are numerous small annoyances connected with their use in camp; the chances are that half the time when they are needed, some will be in the field, getting the topography on perhaps some side line that has been run. In running side lines, too, these are quite liable to come along the edge of a sheet, with perhaps the topography on one side of the line on one sheet and on the other side on another, which adds greatly to the cost of the topography, as well as introducing chances of error.

In arranging the sheets on the drawing table after they have been in use any length of time, it is found that they do not fit well on account of unequal shrinkage or swelling of the paper, and the mechanical difficulties of platting a long line on separate

sheets, and have it always match right, especially where long tangents are to be projected, can only be appreciated by those who have tried both ways. Any one who has worked in camp knows the tendency of the wind to pick up and deposit any kind of loose sheets of paper in perhaps the only mud puddle in a mile. Separate sheets, too, introduce a mechanical difficulty, when stretching a thread over the map, to locate the tangents on account of the edges curling, even if this is very slight.

Aside from all these, which are, after all, only minor difficulties, the principal objection of the writer is, that working on separate sheets, from the very fact that they are separate, and that therefore the map is broken up into several small parts, destroys that broad, comprehensive view of the whole situation which is so essential to the determination of a proper location. As the locating engineer projects his location and works towards the edge of the table, he has to take up all the sheets, tack down and rematch part of them, and some new ones, and then each time he wants to go back and review his work, the same thing has to be repeated. The writer contends that, even after the proper country for the line has been determined, it is only by repeatedly projecting lines, getting their profiles and calculating their cost, that the best line the country affords can be determined, and the roll map offers inestimable advantages over the separate sheet method in that it is more easily accessible for that broad, comprehensive view and review of the whole situation that is absolutely necessary for a proper location.

The advantage (and really the only one worth considering) which is claimed for the separate sheets on railroad location is, that they may be taken into the field, and the topography platted directly on them. The writer believes, in fact, knows from actual experience, and for reasons given elsewhere, that topography can be taken in the field and afterwards transferred to the roll map in the office tent at less expense, provided proper methods are used.

Platting the Preliminary Lines.—There are two methods of platting the preliminary lines; one by latitudes and departures, and the other by laying off the calculated courses from a meridian. The writer prefers the latter, as entailing less work and as producing sufficiently accurate results.

The method of latitudes and departures ensures within the limits of accuracy of the field work, that the actual geographical relation between the two ends of the line is correctly established, but unless a tangent is to be established between these points this information is of no use whatever to the locating engineer or the railroad, and it is time and money wasted getting it. Theoretically the method of latitudes and departures is perfect; in actual practice for railroad location the work necessary for this perfection involves the expenditure of too much time and money for results which can be obtained as well by other less expensive methods.

The line should never be platted by laying off each angle, either with the protractor or by tangent distances from the line immediately preceding it; by this method any error in any one angle is produced to the end of the line, and all errors in platting tend to accumulate. The writer generally lays off the calculated courses (found by adding or subtracting each angle from the assumed or observed course of the first line, as shown in Figs. 19 and 20), by tangent distances from the meridian; a number of courses can be laid off together and transferred with a straight edge and triangle to each point in sucession.

Referring to Fig. 20 (page 51) and the preliminary notes, Fig. 19 (page 58), the general direction of the line is near S 60 E, so a line is laid off down the middle of the roll on which the map is to be platted, and called S 60 E (it may, of course, be any course or the true meridian, as convenience dictates). In this case the variations of the calculated courses from S 60 E are noted in the last column, any point as A is assumed on the meridian line (so called) from this point the various angles are laid off by protractor or by tangent distances (as shown) and the directions of the lines transferred by parallel ruler or two triangles. Thus the direction of 0 to Sta. 20 is parallel to A. 1. Sta. 20 to 24 parallel to A. 2., etc. When these points can no longer be reached conveniently from A, any other point is assumed further along on the meridian line produced.

Many railroads (or their purchasing agents) think that almost any kind of drawing paper will answer for the map, but when it is considered that the final detail map of fifty or sixty miles of line, with the information it contains, costs the railroad from

$10,000 to $15,000 or more, the difference in cost between 25 yards of cheap paper at say 25 cents per yard, and for the best mounted paper at $1 per yard, the difference of less than $20 seems insignificant.

The writer prefers a lightly tinted buff paper to white, as being less trying to the eyes.

In starting the map, care should be taken to so locate the line on the paper that as great a length as possible may be platted without a break. On the C. O. & G. R. R. it was required that the topography should in no place approach nearer than within 6 ins. of the edges of the paper except perhaps at some angle point where it immediately receded from it, and on no account should pieces of paper be pasted along the edge of the map so that the line or the topography might be extended beyond this edge.

The preliminary lines run during the day should be platted each evening by the draughtsman, and checked by the assistant locating engineer or the transitman. This line should be inked in, in red ink the first thing the next morning, the number of the station of each angle point marked, and also each tenth station, the rest of the stations being marked as shown (Fig. 20, p. 51). The draughtsman then plats the topography taken the day previous, which is, of course, at least a day behind the transit work. The topography, having been taken as previously described, requires no particular skill, except mechanical, to transfer it to the map at the reduced scale of this latter. Perpendiculars to the lines should be laid off at each station (light pencil lines that can be afterward erased), and lines drawn parallel to the lines on both sides of it at distances of 100, 200 and 300 ft., respectively, thus reproducing the large squares in the book on the map. Figure 20 shows part of the preliminary line prepared for platting the topography. The contours can then be sketched in through these squares by a good draughtsman sufficiently accurately for the purpose in hand, especially if on 400-ft. to the inch scale; for larger scales, distances out on each station on the perpendicular lines may be scaled to each contour crossing, the points then marked and then afterwards connected as shown in the field book.

Where there is little artificial topography, the writer prefers to ink in the contours in black ink, each 25 ft. contour being accentuated by a much heavier line and the thread of the valleys shown by a bright blue line, thus making the topography stand out and easy to read. Black (drawing ink) for the contours stands the erasing of the many trial lines of the projected location better than colors, but if, as in the case of lines near large centres of population, there is a great deal of artificial topography (streets, lot lines, buildings, etc.), to be shown, it will be better to show the contours in a color, burnt sienna being the most suitable.

The contours should be frequently marked with their elevations, the numbers being preferably in line up and down the hills, as note particularly on maps, Figs. 16 and 26 and sketch (Fig. 31). The author believes that it pays to take considerable care with the

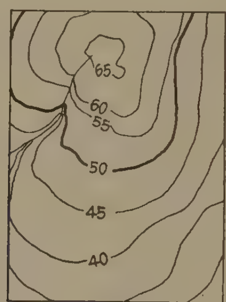


FIG. 31.

map, platting the topograhy clearly, emphasizing each 25-ft. contour, defining the threads of the valleys with blue, and in marking the elevations so that the eye grasps the significant features without effort, and thus enabling the locating engineer to concentrate his mind wholly on the problems of the location.

Projected Location and Profile.—As soon as a sufficiently long stretch of topography has been platted (the length, of course, varying with the kind of country), the projected location will be made by the locating engineer, and as fast as it is completed a profile of it platted by the draftsman from elevations taken from the map, which will usually be called off to him by the locating engineer, who will also fix a grade line, denote the character, dimensions, etc., of the various bridges, culverts,

etc., and indicate any classification of the cuts. The ground line of this profile should be inked in so that it can be seen through the tracing profile if a tracing is to be made. Where the chiefs of various parties in the field are reporting to a central headquarters, tracings of this projected profile should be sent in as soon as each ten-mile section is completed, thus showing exactly what kind of line is being obtained.

Estimate of Quantities.—A careful estimate should be made from this projected profile, the quantities of each cut and fill should be calculated from tables of level cuttings, allowances being made for transverse slopes when these are steep, and the total of each cut and fill marked on the profiles. Where a fill is divided into two parts by a bridge, the quantities of each part should be shown separately. Existing railroads usually furnish standard plans of the various structures, with tables of quantities to be used for these estimates; when these are not furnished the tables at the end of Chapter VIII. may be used, which chapter see also for further information on estimates.

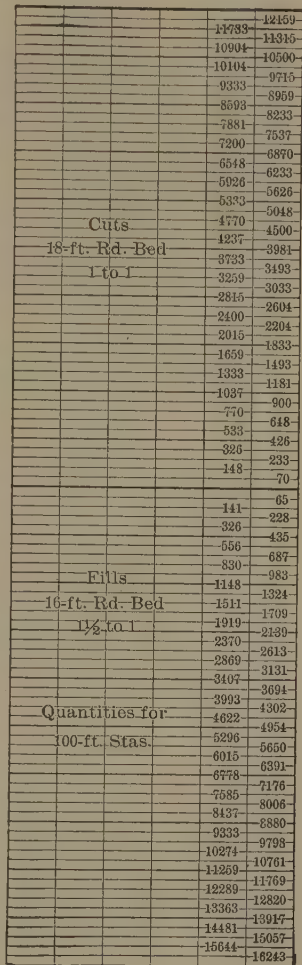


FIG. 32.

In scaling the quantities from the profile, much time may be saved by the use of the quantity scale shown in Fig. 32. This is made on a small piece of the same kind of profile paper on which the profile is platted, the quantities being marked along the side; at each foot the quantity in cubic yards per station of hundred feet, corresponding to the height, above or below the grade line. This scale is moved along the profile, the zero point being kept at the grade line and the quantity appearing opposite the ground line of the profile being

the quantity or number of cubic yards in that station for that average height.

These estimates may be divided to cover each mile, for a section of ten miles, or as required. A good practice is to tabulate the grading quantities in each mile on the profile. Overhaul should be roughly calculated and the best disposition of the excavation studied on the projected profile.

The information developed by a study of the estimates of quantities and cost and of the disposition of material on each projected location, the writer regards as most important; this information can be obtained in no other way and is most essential; and if for no other purpose than to put the locating engineer into that close familiarity with the possibilities of the country, so necessary before the final line can be determined. It will always pay to project and estimate on several lines and not only make an estimate on what is considered as the final line.

Completion of Map.—On the final location, as the line is run in on the ground and tied in to the preliminary, it is inked in on the map, using the ties thus obtained, where up to this time (as the projected location) it had been left in pencil. All land lines are carefully obtained and shown with the plusses, and property owners' names recorded. Bearings on the tangents shown, from the true meridian, and the smaller drainage areas defined.

Location Profile.—The profile of the location should be carefully inked in as soon as platted and checked, alignment and property owners' names shown at the bottom; bridges and other openings noted, as shown (Fig. 27). The grade line should usually be left in pencil until approved, when approval is necessary. A tracing of this profile with all the information should be kept up-to-date, and both profile and tracing made in convenient sections of, say, 25 miles each. As careful an estimate as possible should be made from the profile of the final location and tabulated as shown in Figs. 61 and 62, Chapter VIII., to which refer more particularly in regard to estimates.

The location profile should show all the information necessary for the complete construction of the railroad, with the exception of the details of the structures. The profile of the ground should first be platted and checked, the alignment notes then platted at

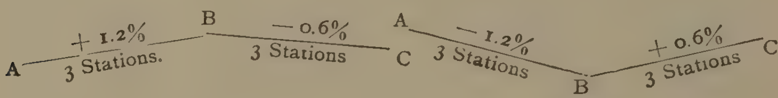
the bottom, as shown (Fig. 27); a heavy line indicating the curves, or a curve may be drawn in showing to the right or left. Any high-water marks should be noted in blue, and any soundings in the cuts or for foundations platted; the grade line should then be fixed, compensation for curves being made wherever necessary, as shown by the alignment notes below; the rates of grade should be shown, and elevations of intersection points. All culverts, bridges, or other structures should then be temporarily fixed, and the quantities in the cuts and fills determined and written in in pencil. The locating engineer should then take the profile into the field and go carefully over the ground, fixing exactly the location, etc., of all structures, and determining the probable character of the excavation and any other details which may affect the final position of the grade line. The final adjustment of the grade line is then made in the office, quantities of excavation, etc., recalculated, the materials in the cuts being classified (rock, hard pan, etc.) according to the best judgment of the locating engineer, from his knowledge of the ground and as shown by the soundings, and proper allowance made for the ditches in the cuts, side ditches, changes of channels, etc.; and these final results marked on the profile, and the distribution of the materials worked out and their disposition shown. The approximate quantities in each structure are shown near it, and a tabulation of the quantities in each mile made and shown. The necessary width of right of way is then shown, as well as property lines, owners' names, etc., mile posts fixed, character of the country, that is, cultivated, wooded, etc., noted, so that the probable amount and location of the clearing can be seen, B. M.'s described, and transit points shown on the alignment sketch at the bottom. This profile and the tracing of it on profile tracing paper can be kept up within a few days of the staking out of the line, so that it can be available, if necessary, for contractors practically as soon as the location is completed.

Vertical Curves should be calculated and platted at all intersections of grades where the change in rate is 0.3 per cent. or more (see page 117). Henck's formula for the calculation of these curves is given below, the curve thus obtained being a parabola.

Let g and g^1 = the two intersecting grades. (Rate per station.)
n = the required number of stations on either side of the point of intersection.
a = change in rate for first station
Then using the following formula, the value of a is found

$$a = \frac{g - g^1}{4\,n.}$$

Care must be taken to keep the signs algebraically correct, taking the grades in continuous order thus:



Case 1. Case 2.

Case 1 $(n = 3)$

$$a = \frac{1.2 - (-0.6)}{4 \times 3} = \frac{1.2 + 0.6}{12} = \frac{1.8}{12} = .15$$

Case 2 $(n = 3)$

$$a = \frac{-1.2 - (+0.6)}{4 \times 3} = \frac{-1.2 - 0.6}{12} = \frac{-1.8}{12} = -.15$$

Then, starting from one end, taking always the beginning, and working in the same direction all the time (generally in the direction of the stationing, though this is immaterial).

The rate of grade for the 1st station will be $g - a$.

In Case 1.

$1.2 - 0.15 = 1.05$

In Case 2.

$-1.2 - (-.15) = -1.05$

Then, adding algebraically $-2a$ to this rate of grade, the rates are found for each sucessive station, thus:

Case 1.

$$\begin{array}{r} +\ 1.05 \\ \underline{-\ \ .30} \\ +\ \ .75 \\ \underline{-\ \ .30} \\ +\ \ .45 \\ \underline{-\ \ .30} \\ +\ \ .15 \\ \underline{-\ \ .30} \\ -\ \ .15 \\ \underline{-\ \ .30} \\ -\ \ .45 \end{array}$$

Case 2.

$$\begin{array}{r} -\ 1.05 \\ \underline{+\ \ .30} \\ -\ \ .75 \\ \underline{+\ \ .30} \\ -\ \ .45 \\ \underline{+\ \ .30} \\ -\ \ .15 \\ \underline{+\ \ .30} \\ +\ \ .15 \\ \underline{+\ \ .30} \\ +\ \ .45 \end{array}$$

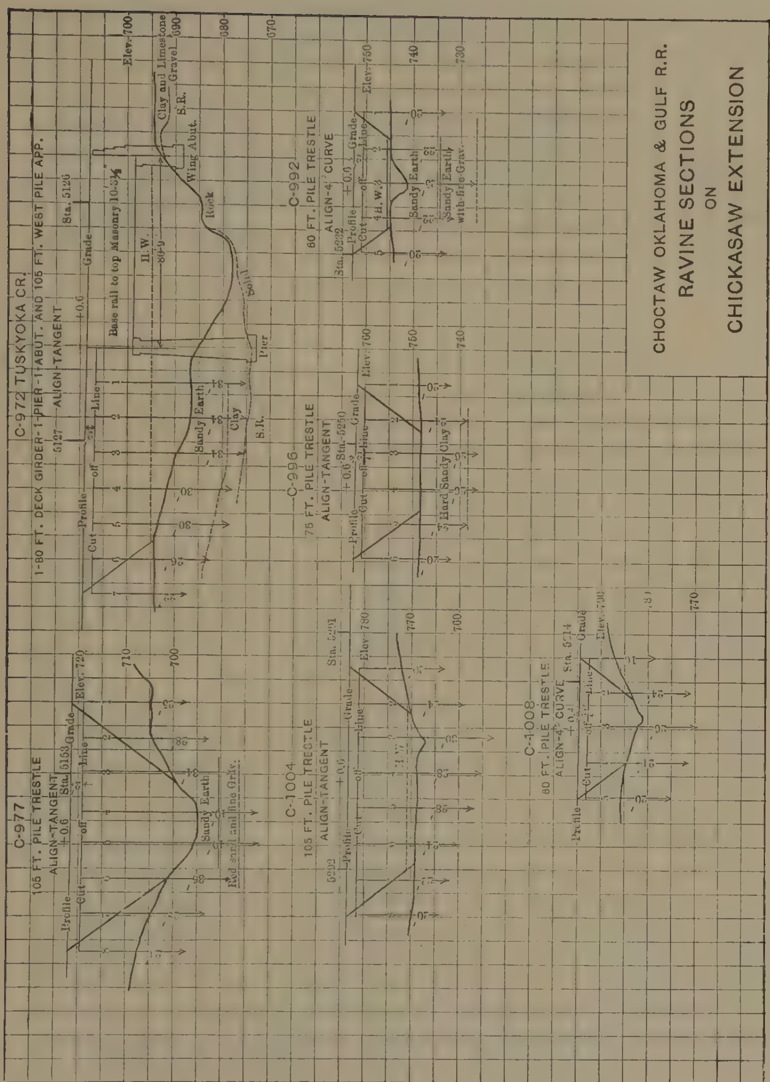

CHOCTAW OKLAHOMA & GULF R.R.
RAVINE SECTIONS
ON
CHICKASAW EXTENSION
C-972 TUSKYOKA CR.
1-80 FT. DECK GIRDER-1-PIER-1-ABUT. AND 105 FT. WEST PILE APP.
ALIGN-TANGENT
C-977
105 FT. PILE TRESTLE
ALIGN-TANGENT
C-992
60 FT. PILE TRESTLE
ALIGN-4° CURVE
C-996
75 FT. PILE TRESTLE
ALIGN-TANGENT
C-1004
105 FT. PILE TRESTLE
ALIGN-TANGENT
C-1008
60 FT. PILE TRESTLE
ALIGN-4° CURVE

FIG.

Then, finding by calculation the elevation of the point A, which, supposing B = Elev. 96.00 would be

In Case 1.	In Case 2.
92.4	= 99.6

and adding algebraically to these, the varying rates of grade per station, gives the elevation of each station on the vertical curve, thus:

	Case 1.	Case 2.
Elevation at A	92.4	99.6
	+ 1.05	− 1.05
	93.45	98.55
	+ .75	− .75
	94.20	97.80
	+ .45	− .45
	94.65	97.35
	+ .15	.15
	94.80	97 20
	− .15	+ .15
	94.65	97 35
	− .45	+ .45
Elevation at C.	94.20	97.80

Elevation at C. by calculation from B:

In Case 1.	In Case 2.
$96 - (3 \times 0.6)$	$96 + (3 \times 0.6)$
$= 94.20$	97.80

The rate of grade used must be the rate per station. Where the stations are 100 ft. this will correspond, of course, to the rate per cent. as used on the profile. If it is desired to calculate the grade for intermediate points, say 50 or 25 ft., in the first instance the rates would be 0.6 and 0.3, respectively, and in the second 0.3 and 0.15, and in these cases also, if it was required to preserve the length of curve the same, viz.: 600 ft., the number of stations would be increased to 6 and 12, respectively, on either side of the apex.

Ravine Sections or large scale profiles (usually 10 ft. to the inch) should be made of all bridge sites where pile bridges or trestles are required (see Fig. 33), and situation plans for all sites where masonry is to be built. For arches, etc., a cross-section ground plan showing elevations at 10 or 20 ft. squares is usually made. Figure 57 shows a site plan for a highway crossing.

Right of Way Map.—Figure 49 shows a portion of a right of way map through country where the land has been laid out by the Public Lands Survey, the extra width being taken to provide for slopes of embankment. Such a right of way map should always show enough to show the relation of the right of way to the remainder of the property of the various owners, as well as dimensions, areas, etc., of the part taken for the railroad.

The office work should always be kept close up with the prog-

ress of the survey, as it is only by doing this that the value of the line run can be properly appreciated and the necessity of changes, which often are not apparent until the final data are being compiled, shown before the party gets away from the vicinity; not only is this necessary, but as soon as the survey is completed, the data should be immediately available for contractors whom the company may wish to bid on the work, and all the information accumulated during the survey which can help them in arriving at a proper estimate, in such shape as to be easily and readily available.

CHAPTER VI.

LOCATION.

The work of the survey having now progressed to the point where all the data which can affect the location have been properly compiled and arranged, that is to say, that a topographical map has been completed, covering the whole situation, we can now proceed to lay out or project on this map the line on which the railroad is to be built; in other words, the location. The line on the map being known as the projected location, the actual or final location being this line as actually staked out on the ground.

It should not be inferred, however, that no attempt should be made to project any location until all the data are complete, or before the whole country has been thoroughly explored. As the survey progresses and as the topography is platted on the map, a projection should be kept up closely to date, a projected location and profile being made to correspond to every preliminary line run.

On projecting the location after the first preliminary has been run, it will often be found that owing to errors in sizing up the country in the field, shortening of the line, etc., changing the grade, or many other causes, the preliminary has not covered the proper ground, thus necessitating running another preliminary; or the study of the map necessary for the first projection will develop new possibilities not at first anticipated, new combinations of the line under consideration, with other lines, etc., all or any of which may necessitate further preliminary or spur lines, to properly develop the country, so that in all cases a projected location should be kept close up, that the general study of the situation will develop all the possibilities, and all the necessary preliminary lines be run before the party or camp is moved too far ahead. Every line projected, whether good or bad, and especially the study of the profiles of them by fixing a grade line and making an estimate adds much valuable information to the engineer's knowledge of the country.

The necessity of giving much time and attention to projecting various lines, getting their profiles and making an estimate of the quantities, cost of construction, and particularly of the disposition of the material, cannot be too strongly emphasized; in no other way can the engineer get the necessary intimate knowledge of the details of the country or get into such close touch with the topography.

Intuition and eye for country, and imagination, as has been previously stated, are very necessary, but it takes time and study for the details to soak in, and until the engineer is thoroughly steeped with the details and peculiarities of the particular piece of country he is working in, he has not the knowledge necessary to make a proper location.

The addition of a field draughtsman and an assistant engineer to the locating parties is a comparatively recent practice, at least to any extent, and even now is not nearly as general as it should be, the omission resulting in the chief of the party being tied down to details of the field work and the drafting, and preventing almost altogether his devoting his time as he should, either to a proper examination of the country as a whole or to a study of the facts developed by the survey, and precludes almost entirely this study of the profiles and estimates of projected locations, which is absolutely essential to a proper appreciation of the country.

Even in localities where the possibilities are confined to one route, it can safely be said that the first line selected is never the best; how much more, therefore, is this liable to be true where there is a choice of many or at least more than one good route, or a combination of routes.

Every engineer with experience in location knows that there is practically no limit to which revisions of even very good lines may be carried and still save money on construction. Of course, the time comes when the cost of making the revisions exceeds the saving in construction, and this is theoretically the economic limit to which this work should be carried. In actual practice, however, time is generally an important factor, and a line of some kind has to be staked out for construction within a certain limited period.

The fact, however, that even with the best of locating engineers and after a thoroughly conscientious study of the situation, revis-

ions are still possible, and profitable, is so well recognized by railroad managers with experience in location and construction, that they make it a practice to send a second locating party over every line to revise the locations, no matter by whom made, though it should seldom be the case that these revisions should need to be of anything but details of the line. It might be said that a line was well located, even though revisions of details of alignment, or in fixing grade lines might still be possible, or where, by shifting the line slightly, better grades might be obtained, and the cost of construction lowered, but it could never be said that a good location had been made when the line was not in the right country, no matter how great a perfection had been reached in the refinement of details. Every energy of the locator, therefore, should be bent toward getting his line in the right country, and generally correct, especially if his time is limited, trusting that an opportunity may be offered later to refine the details, if this cannot be done at first.

All this should show to the locating engineer with the limited time at his disposal even on work where every consideration is given to the fact that time for study of the location is absolutely necessary, that nothing should be neglected which tends to direct these studies in the right direction and confine them to essentials, in order that the line may be at least in the right country, and that especially where time is a factor, the alignment and grade are generally correct, at least.

The reconnaissance should have shown what parts of the country needed development in detail, and the preliminary lines and topography should have developed all the possibilities, but the study of details and their significance must be made in the office; and in no other way can the value of proposed lines be better estimated and brought out than by actually projecting them on the map, obtaining their profiles and realizing their significance by estimating the quantities involved, studying the disposition of the materials, possible difficulties of construction, and getting an idea of their value from the final standpoint of operation.

In laying out the projected location, a spool of fine, strong, black silk or thread, preferably the former, is necessary. Stretched tightly between the two hands over the map, the positions of the tangents can then be studied to the best advantage, shifting the

thread back and forth until it appears to lay in the best position, where points may be marked and a line drawn lightly in pencil. The writer believes there is no other way whereby the tangents can be fitted to the ground so well or so easily as by this method. In fixing the grade line, also on the profile, the thread will be found almost absolutely necessary, as in no other way can the effects of changes be so readily seen.

The various curves liable to be used should be drawn at the same scale as the map, on a sheet of tracing cloth in a fine ink line, as shown (Fig. 34). This sheet can then be laid over the map and shifted back and forth until a curve is found which best fits the topography, when the necessary points can be pricked through to mark it. Tangents should be drawn at the ends of

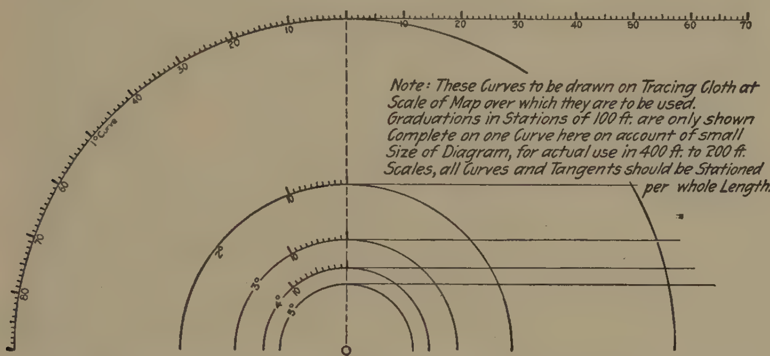


FIG. 34.—CURVE DIAGRAM FOR PROJECTING LOCATION ON MAP.

the curves and 100-ft. stations marked on them, so that if necessary small sections of profile may be read off directly through the tracing cloth, without its being necessary to draw the line on the map.

Sheets of celluloid, with curves drawn at a scale of 200 ft. to the inch, which are useful in mountain location, are made and sold by dealers in drawing materials.

When a line is selected which appears to best fit the ground, it can be drawn lightly in pencil on the map, laid off in 100 ft. stations, and a profile of it platted from the contours. Usually the profile will show that changes in the line are necessary, these changes being made until finally a profile is obtained which ap-

pears to be all right. On this profile a grade line should be fixed and the quantities in the cuts and fills calculated from tables of level cuttings, and the disposition of the material studied. This may involve further changes in the line or grade, or both, and so the whole thing is worked back and forth until a satisfactory line is obtained. This process may involve, and often does, the comparison of two or more lines by the calculation of the quantities and cost of each; that is to say, two or more lines through the same locality as distinct from two or more, more or less widely separated routes.

When a line is finally determined it should be drawn carefully on the map in pencil, the beginning and end of each curve indicated by radial lines, stationed continuously from the beginning, and a continuous profile of it platted from the contours on the map, this being the projected profile; a grade line is then laid on this profile, sizes and location of all bridges, culverts, etc., indicated by the locating engineer, as well as the probable amount of rock excavation, etc., so that the draughtsman can then make up an estimate of the quantities and cost. This projected profile should have almost the same information on it as the location profile (Fig. 27), the width of right of way, names of property owners, records of bench marks, notes at the top (pasture, timber, etc.) being omitted.

The writer's practice has usually been, to try and get back to camp about 4 P. M. each day and project a location on that portion of the map on which the topography had been platted that morning. The map is generally in use in the evening by the transitman and draughtsman to plat the line run during the day, and by the draughtsman in the morning getting on the contours; and as it is important to keep the projected location as close up to the end of the line as possible, this arrangement has proven most satisfactory. In country where long tangents are numerous, it may be necessary, of course, to leave the projected location until there are several days' work ahead so that a long stretch may be examined at one time; still, the map should be studied each day to see that the preliminary lines have been run in such a way that the topography covers the ground where the projected location is liable to lie. In rough country, where curves are numerous, it is more necessary to keep the projection close up, as

there is then more likelihood that it will be necessary to run further preliminary lines in order to properly cover the country, this being especially so when running grade lines.

It is in making this projected location that the engineer will necessarily use all his skill. The writer would again emphasize the fact that this work should only be done by the man who is thoroughly familiar with the ground; no maps can convey all the information, nor can a study of the ground alone develop it all; they must be carried on together, and the man who has done all the work up to this point should project the location, and only the continuous progressive study of various projected lines and combinations of lines will enable the engineer to say finally, "This is the best line." Of course, ability to select this line, even after the maps have been properly made, depends entirely on the engineer's own skill and experience, and hardly at all on any rules or instructions which may be obtained from books. One rule, however, always holds good: Lay out the line of best alignment and grades first, and afterwards cheapen the construction if you have to.

While good alignment is very essential, and no pains should be spared to obtain the best possible, the fact must never be lost sight of that grades are equally, if not more important; in fact, they are almost invariably the chief factors in the cost of operation, and require the most careful study to eliminate unnecessary rise and fall, and to avoid steeper ruling grades than the country necessitates. At the same time, the study of the whole situation on a properly constructed topographical map, after becoming thoroughly familiar with the ground, will invariably result in better alignment for the same or less cost than is in any way possible by the study of the ground or the map alone or little patches of either.

One of the most difficult problems in working out the details of location is the location of a grade line; that is, the location of a more or less long stretch of line on the ruling grade, sometimes called a supported line. The problem would be comparatively simple were it not for the necessity of compensating the grade for curvature. If a straight grade, uncompensated, was required, all that would be necessary, having assumed the summit cut, and

consequently the elevation of the grade line at the summit, would be to find ground to support the grade, the elevation at any point being fixed by the distance from the summit, and the rate of grade. Compensation for curvature introduces a complication, however, in that the rate of grade varies with the amount of curvature introduced. Thus, supposing a maximum grade of 2.0 per cent. is to be used on tangents, if a tangent 5,000 ft. long be located, the lower end may be 100 ft. lower than the upper; if light curvature be introduced, say 10 stations of 1° curve and 15 of 2°, and compensation be assumed at 0.04 per cent. per degree of curvature, we shall have 10 stations of 1.96 per cent. grade, 15 stations of 1.92 per cent. grade, and the balance, 25 stations, on tangent on the 2.00 per cent. grade; the total fall on this line, therefore, could be only 98.4 ft.

On much mountain location where 2 per cent. grades would be used, much curvature would probably be introduced, say approximately on 5,000 ft. of line, there might be 10 stations of 8° curve on which the grade, assuming a compensation of 0.04 per cent. per degree, would be 1.68 per cent., 12 stations of 7° curve on which the grade would be 1.72 per cent., 8 stations of 5° with a grade of 1.80 per cent., the rest of the line, 20 stations, on tangent with 2.00 per cent. grade, thus limiting the total fall of the line in 5,000 ft. to 91.84 ft.

It will be noticed that the total fall on any line on maximum grade compensated for curvature is equal to the number of stations multiplied by the maximum grade, less the total number of degrees of curvature (total degrees of central angle), multiplied by the compensation per degree. Thus in the last example, 50 stations on 2.00 per cent. grade = 100 ft. rise or fall. Total number of degrees central angle 204, compensation .04 per degree of curve per station, total deduction $204 \times 0.04 = 8.16$ ft., $100 - 8.16 = 91.84$ ft.

The amount of compensation for curvature is usually assumed to be the same per degree for any degree of curve; thus, if it be assumed at 0.04 per cent. per degree, a 1° curve would be compensated 0.04 per station, and a 6° curve 0.24 per station.

It is generally conceded, however, that the resistance due to curvature does not increase proportionately as the degree of

curve, and the writer prefers to use a sliding scale somewhat as follows:

Curves of 2° and less	....	0.06% per degree.
2° to 4°	....	0.05% " "
4° to 8°	....	0.04% " "
8° to 14°	....	0.03% " "

The proper amount of compensation for curves is one on which opinions vary, and which varies with the state of the track, type of engine, etc.; where curves are few, and, therefore, probably of large radius, the compensation can be increased to as much as 0.1 per cent per degree, with little probability of increasing the cost of construction, and any error will surely be on the right side. On long ascents, where often every inch counts, and where often a high rate of compensation will mean a higher rate per cent. on tangents or a much longer line, compensation as low as 0.03 per cent. for all curves will probably be sufficient.

The above table is intended only as an approximation and suggestion. It is seen, of course, that if used literally, a 9° curve, for instance, is compensated less than an 8°. It is not advisable to introduce thousandths in the rate of grade, and tables can be made up based on this idea to suit the range of curves used in each particular case.

It will then be seen that a most important point in locating long lines on ruling grades is the avoidance of curvature as far as possible. More curvature means less rate of grade, and therefore longer line. Always lay out, first, the line with the best alignment possible, even though it apparently involves extremely heavy work, and work from this line, if necessary, to one having more curvature to cut down the work. It will often be found, by carefully comparing the lines, that the line with the most curvature, although giving a good looking profile, will be the most expensive by reason of its length, even without counting the increased cost of operation by reason of the excessive curvature.

Both the preliminary lines, and the projected location, of grade lines, should be started at the summit and worked down. It will be well at the start to assume some average rate of grade, somewhat less than the maximum. Thus, for instance, in the case last noted, the average rate per station for the whole 5,000 ft. was about 1.84 per cent., and in ordinary mountain country about 1.8 per cent. will be a fair average to assume for a 2 per cent.

maximum for the location. Perhaps 1.7 per cent. would be a better rate for the preliminary, as usually the located line will be shorter.

A summit cut being then assumed, and the average probable rate of grade decided on, the preliminary line will follow along, finding such country as will support this grade. In other words, the position of the preliminary line up and down the hillsides of the valley will be governed by the elevation. These are the cases where a good leveller is absolutely necessary; he must keep close behind the transit party, so that the chief of the party can keep continuously in touch with him to know how to run the transit line. Much information can be obtained also by an intelligent use of the stadia wires in the transit, and the vertical arc and gradienter screw in approximating elevations and determining where to run the line.

In cases of long supported lines, as these lines are usually called, some kind of a rough projection must be made each night covering the preliminary run during the day, so that a check on the assumed amount of curvature (in other words, the rate of grade) can be obtained.

Many devices, such as loops. horse-shoe curves, switchbacks, etc., have to be resorted to at times to lengthen the line in order to get the necessary distance in which to get down.

There is no special skill needed in this work except an aptitude for fitting the line to the topography over that employed in the location of a railroad anywhere. Of course, much diligent search is necessary at times to find country to support the grade line, and training and experience are necessary to see the possibilities. We have heard of engineers getting a line through some particular pass, and, by a series of tunnels and loops, finally getting the line down to the plains, where others have failed; and the writer would be the last man in the world to deny them all the credit which is theirs; but he does not believe that there is any problem of this kind which any locating engineer, worthy of the name, should not solve with his ordinary equipment of common sense, knowledge of his profession, and sufficient training and experience. It certainly requires no specially God-given sense, but rather persistence, hard work, and common intelligence.

Fig. 35 shows a plan and profile of the famous Georgetown Loop on the Colorado & Southern Ry., reproduced through the courtesy of Mr. H. W. Cowan, Chief Engineer; and Figs. 36* and 37* maps of parts of the Albula Branch of the Rhaetian Rys., in Switzerland, showing some very extensive and complicated developments necessary in the descent through the Albula valley, at the head of which is the Albula tunnel, nearly four miles in length. The gauge of this railway is 1 meter = 3.28 ft., is a single-track road, and has maximum grades of 3.5%, with curves of a radius as small as 100 meters = 328 feet. Figs. 38 and 39 show plan and profiles of a line recently located and built in Arizona, giving excellent examples of switchback location and construc-

FIG. 38.

tion. The following description of the line, as well as the accompanying plates, is reproduced from Engineering News of June 21, 1906:

"The total length of the line is 28 miles, and the ascent of 2,436 ft. between Turkey Creek and Crown King is accomplished in a distance of 17 miles. The total distance between the first and last switchbacks is nine miles, with a difference in elevation of 1,328 ft. There are ten switchbacks, with five back-up sections of line. These sections are from 1,500 to 4,000 ft. in length, and have slightly easier grades and curves than the go-ahead sections, in order to give the trains a little advantage when backing up. The tails of the back-up sections are at present about 300 ft. long and are continued on a rising grade of 2% beyond the switchstands, the maximum grade approaching the switchstands being

*From Engineering News, Dec. 19, 1901.

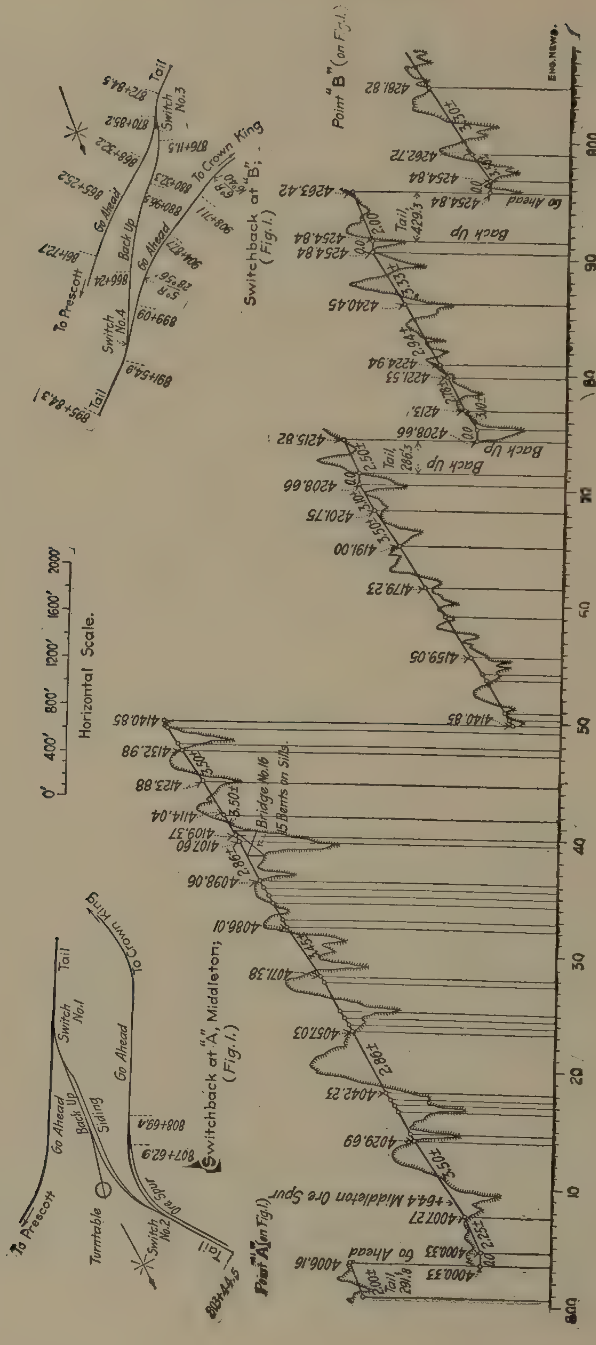

Horizontal Scale.
0' 400' 800' 1200' 1600' 2000'
Switchback at "A", Middleton; (Fig. 1.)
Switchback at "B", (Fig. 1.)
Point "A" (on Fig. 1.)
Point "B" (on Fig. 1.)
To Prescott
To Crown King
Turntable
Go Ahead
Back Up
Siding
Switch No. 1
Switch No. 2
Switch No. 3
Switch No. 4
Ore Spur
Tail
+64.4 Middleton Ore Spur
Bridge No. 16
15 Bents on Sills
Eng. News.

FIG. 32.

3½%. The frogs are No. 6½ and No. 9. Fig. 39 shows a profile of part of the switchback line, with plans of two of the switchbacks. The track is laid with 65-lb. rails, and on the 16° curves the gauge is widened ¾-in."

"The engines used are of the consolidation (2-8-0) type, with a rigid wheelbase of 13 ft. 6 ins., and the weight of engine and train is about 226 tons. The average speed over the switchback section of the line is about 15 miles per hour. Mr. Drake* states that the train crew has become so handy at the work, that a brakeman drops off the last car as it passes the switch, and the engine is backing before a passenger can hardly realize that the train has been stopped."

In locating switchbacks, care must be taken to make a reasonable allowance for a possible increase in the length of the stems to accommodate longer trains than those to be used at first. The stems often end near the upper end of a tributary valley, and the writer has seen one or two instances where, on account of the end of the stem being so close to the head of the valley, the extensions necessary to accommodate trains of four or five cars more than the line was originally designed for, cost almost as much as the original line.

The grade through the switch and for a distance of, say, 15 or 20 feet at either end, beyond the frog, and point of switch should be level or with a very slight grade for drainage if necessary, the grade on the stem gradually ascending to the end in a long vertical curve, the steepest part of which should be somewhat less than the maximum grade on the line, this ascending grade on the stem having the double advantage of aiding in stopping and starting trains without the necessity of applying the full power of the brakes or releasing the same.

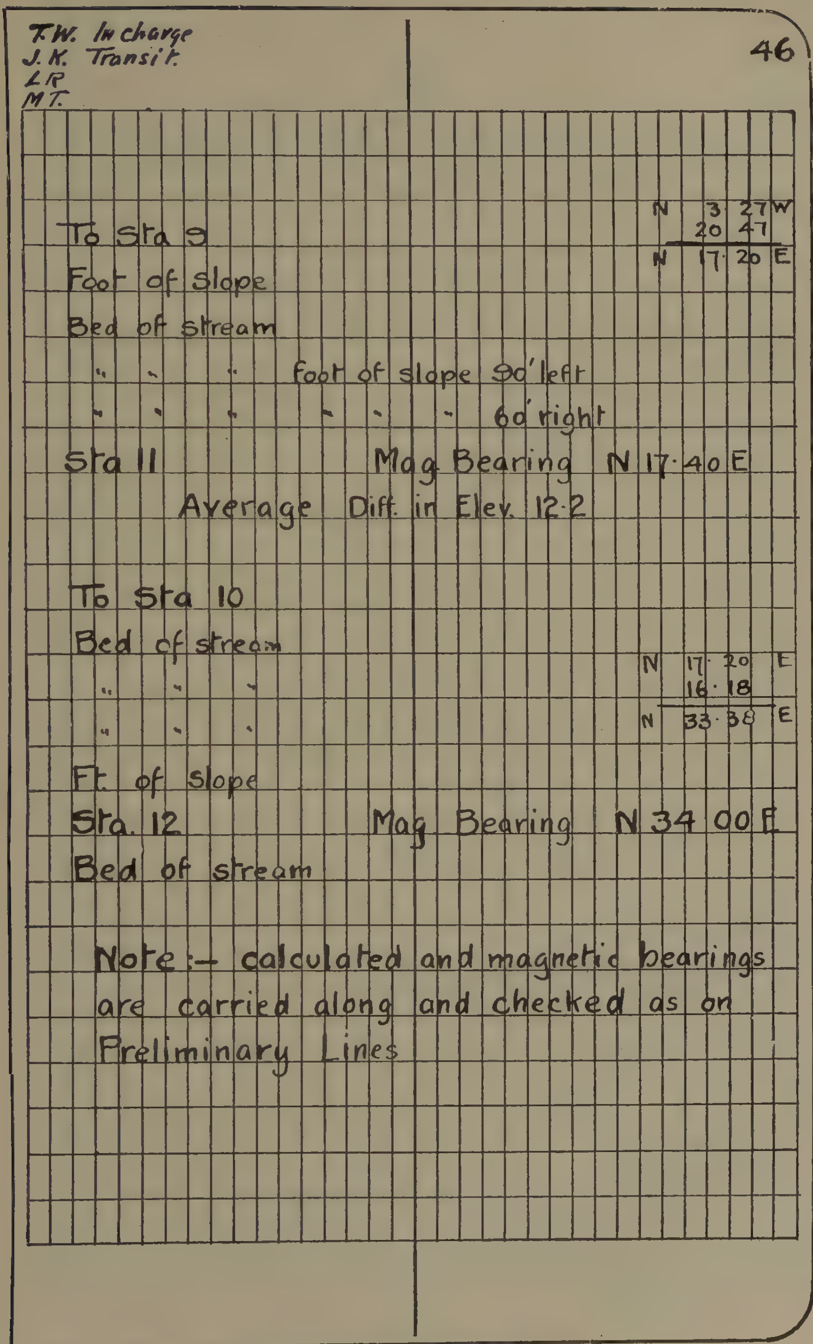
No determination as to the rate of grade to be used on long descents in mountainous country should be made until very thorough preliminary explorations of the country have been made. The stadia can be used here to perhaps better advantage than anywhere, and a rough skeleton survey of the whole country, within the limits of where the line can possibly lie, should be made. The words, "rough skeleton survey" are used advisedly, as at this stage of the work detailed topography should not be

*W. A. Drake, M. Am. Soc. C. E., Gen'l Supt. and Chief Engineer, Crown King extension of the Santa Fe, Prescott and Phoenix Ry.

Dist	Ang	V.Ang	Correct'd Dist	Diff in Elev	Elevation
Instrument at 10 (Elev 739·4) Zero on Sta 9					
△ 563	0°·00′	+0°·35′		+5·74	745·14
234	140·30	−0·10		−0·7	738·7
148	178·50	−2−30		−6·5	732·9
273	186·40	−1·58		−9·3	730·1
381	166·	−1·43		−11·4	728·
△ 548	159·13	−1·14	547·73	−11·8	727·6
Inst at 11 (Elev 727·2) Zero on Sta 10					
△ 546	0°·00′	+1·19	545·73	+12·6	739·8
110	317·50	0·00			727·2
48	270·	−1·29		−1·2	726·
133	163·	−0·57		−2·2	725·
252	168·20	0·0			727·2
△ 523	163·42	−1·34	522·6	−14·3	712·9
248	145·20	−0·59		4·2	723

Note:— Distance and Vertical angle read both backward and forward between instrument points and the average taken. All angles from 0° to 360° to the left. 0° on backsight

FIG. 40.—TYPICAL STADIA NOTES.



T.W. In charge
J.K. Transit
L.R.
M.T.

46

N 3 27 W
20 47
N 17 20 E

To Sta 9
Foot of slope
Bed of stream
" " " foot of slope 90' left
" " " " " " 60' right
Sta 11 Mag Bearing N 17·40 E
Average Diff. in Elev. 12·2

To Sta 10
Bed of stream
" " "
" " "

N 17·20 E
16·18
N 33·38 E

Ft. of slope
Sta. 12 Mag Bearing N 34 00 E
Bed of stream

Note:— calculated and magnetic bearings are carried along and checked as on Preliminary Lines

FIG. 40.—TYPICAL STADIA NOTES.

taken. Lines should be run, as for a preliminary, except that no stakes need be driven except at instrument points, and the notes can be kept in the same way, as far as the line is concerned. The record for the stadia shots can be kept as shown (Fig. 40), and the information obtained will be solely a development of the salient points and general characteristics of the country. Especial pains should be taken to ascertain what the general rate of descent is in the valley below the first abrupt drop from the summit, as this will probably have the greatest influence in the final rate of grade selected. Table 17 gives the necessary data for the reduction of the stadia, readings and notes.

There will generally be a mile or two, or possibly more, near the head of a valley where apparently, at first sight, very heavy grades are necessary, though below this, lighter grades may be possible for a much longer distance; the attention of the locator, therefore, will then be turned to investigating the possibilities of carrying the lighter grade through to the summit, in other words, investigating the possibilities of developing or lengthening the upper part of his line, or of resorting to a tunnel, or heavier summit cut.

Fig. 41 shows such a development. The general grade of the valley between A and B was about 2.6%, and 2% compensated (0.07% per degree, metric curves) for curvature was adopted as the maximum grade, development being necessary at both top and bottom of the valley, the summit in this case being an elevated plain, and an abrupt descent of the stream through a box cañon at the bottom, precluding the possibility of following it below B.

In this case, the ability to get a fairly good line on a certain grade between the points A and B was the controlling factor in the situation, as is often the case.

These points must be determined by the preliminary reconnaissance before actual lines are run and topography taken. The same general principles govern in mountain location, and in the most difficult country as everywhere.

The area must first be thoroughly investigated before grades are determined even tentatively. In country requiring heavy grades the preliminary reconnaissance must be in more detail, and give more exact information by actual, even though rough

measurements; in rolling country requiring lighter grades, tentative routes and grades can be determined from the reconnaissance without the use of instruments other than the hand level; but the possibilities of various widely separated routes can only be determined by actual surveys, and estimates from projected locations; in mountain country one route is often so conspicuously superior as to determine its availability at once, leaving only the details of that route to be determined, whereas in rolling country the difficult problem is the selection of the route.

In working out the details of the location on a long section of maximum grade after the preliminary has been run and the map completed, a tentative line with curves should be laid out on the map, stationed, and the grades computed, allowing the compensation for the curves; then opposite each station on the map mark a point at which the elevation of the ground, as shown by the contours, corresponds to the grade of the station, and then through these points sketch, lightly in pencil, a continuous line, which will be the *grade contour;* showing graphically on the map where and in which direction the projected line departs from a line on which there would be no cut or fill, thus showing at a glance in which direction the line must be moved at any point to improve the profile. (See Fig. 41.)

Then, by repeating the various processes of adjusting the line, platting the profile, and calculating the quantities, working back and forth from one to the other, a line will finally be obtained which will fit the ground as well as the skill of the engineer will permit.

Where possible, grades should always be compensated for curvature, whether they are maximum grades or not, provided, however, that such compensation of grades less than the maximum does not unduly affect the cost. The ideal line, from the operating standpoint, as regards fuel economy, and to a certain extent the wear and tear on rolling stock, is one where the differences in resistance, due to varying curves and rates of grades, are reduced to a minimum; in other words, where, with a constant head of steam, the throttle can be set at a certain point and the train will "pull just the same all the way." Thus, for example, on a line with, say, 1.00% maximum grades; on a certain part of the line, a continuous grade of 0.7% may be possible

for some distance, involving one or more curves and intermediate tangents; it will be better to endeavor to find ground on which the grades may be so adjusted that the grade may be increased slightly on the tangents and reduced on the curves. Thus, suppose on 5,000 ft. the grade which best fits the ground is 0.7%; on the 5,000-ft. are 20 stations of 2° curve, and 15 stations of 3° curve, involving for a compensation of 0.04 per degree 3.4 ft. of elevation.

The total rise in 5,000 ft. at 0.7% equals 35.00 ft., add amount of compensation, 3.4 ft. = 38.4 ft., which, divided by 50, gives 0.768 as the rate of grade which can be used on the tangents, and compensated 0.4 per degree on curves, and reach the same elevation. This compensation of grades less than the ruling grade is a small refinement, and should not be resorted to where any appreciable expense is incurred in the construction; but there are many places where it might be done and improve the line, at the same time not increase the cost.

It is well, where possible, to avoid the use of rates of grade involving two or more places of decimals, fixing the rate to the nearest even tenth. Of course, on long stretches of supported line on maximum grade, where often every inch counts, this cannot be done. So also it will seldom be found necessary to use curves with anything but indices of even degrees, thus saving much work, both in laying out the line and on construction, besides being of much benefit on maintenance work later, where a very few tables dealing with only a few different curves can be made up for the use of the trackmen.

The writer, at one time, objected seriously to these limitations of grades and curves, believing that a nicer adjustment of the line could be made by using any degree of curve with indices of odd minutes, when necessary, and grades, the rates of which were figured even to three places of decimals, but found by actual experience that the even tenths, and even degrees of curves, could almost invariably be used to equal advantage, but required possibly at times a closer study of the situation. Of course, no rules of this kind can be absolutely ironclad, but they will be found to apply far oftener than is usually supposed if one is compelled to abide by them.

No P. C. or P. T. should be allowed to fall on a bridge, and

the ends of curves should be kept at least 400 feet away from the ends of all bridges, if this can possibly be done, and especially so in the case of wooden trestles.

Broken back curves or two curves in the same direction, joined by a short tangent, should be absolutely prohibited anywhere; some kind of a curve or a compound curve, spiralized, can always be found to cover the same ground.

Reversed curves also should not be allowed; at least, sufficient tangent should be obtained to allow the elevation of the outer rail to be properly taken care of, and necessary spirals introduced between two curves in opposite directions.

No curve less than 400 feet long should be used.

Care should be taken in fixing grade lines to allow for stations. If a station is necessary on a stretch of ruling grade a break should be introduced, allowing at least three or four hundred feet of level grade beyond where the engine will stop on the upper side of the station, as well as level grade enough for the expected length of the trains. See following paragraphs in relation to virtual grades.

Vertical curves should be introduced at all breaks in grade where the change in rate is 0.3% or more, and the curves should be of such length as to limit the change of rate between any two stations to this amount. In sags they should be as much longer than this would require as possible. (See page 95.)

Breaks for compensation should always be made at even stations nearest the ends of the curves. The writer has seen profiles where the breaks for compensation were made at exactly the P. C. and P. T. of the curve, elevations and rates being figured to thousandths of a foot. The futility of this is apparent when we reflect that the rate of compensation is an approximation only, the resistance of each particular curve varying with the state of the track, the weather, type of engine, etc., and the work incident to calculating odd rates of grade, therefore of no particular use. As a rule, summits of grades should be avoided on embankments and depressions in cuts, the latter most particularly, on account of the expense and difficulty of drainage. Even level grades through cuts of any length should not be used, at least 0.2% being necessary for proper drainage of the ditches. Slight undulations of the grade line involving rates of grade not higher than 0.2%, or depressions with a total ver-

tical height of 10 feet, have very little if any effect on operating expenses. On grade revisions of old lines, where operating conditions can be predicted for the future with more or less confidence, much deeper sags than this can be calculated to be operated with no increase in operating expenses. (See also Virtual Grades.)

In fixing the grade line on the profile, care must be taken to keep the line always high enough to be out of the water. Elevations of high water-marks should have been taken by the leveller and marked on the profile, and the grade line must be fixed to allow for the free passage of water underneath the completed structure.

Shallow rock cuts should especially be avoided, as such rock excavation is very expensive, and whilst the contractor, of

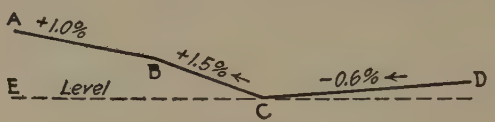


FIG. 42.

course, generally bids one price for all the rock on the line, he will in all probability have made that price high enough for all the rock to cover the extra expense on any particular part or parts. And even then there is always a great deal of trouble in getting the work done properly.

Virtual and Momentum Grades.—It is permissible at times, and often desirable, to introduce short stretches of grade steeper than the ruling grade, where the momentum of the approaching train can be used to overcome the resistance on these grades over and above that on the ruling grades; in other words, where it is possible to get a "run at the hill," as, for instance: On a line with ruling grades of, say, 1.0%, it might be desirable to introduce a short stretch of perhaps 1.5% as shown in the profile, Fig. 42.

A train loaded so that the engine can just haul it up the 1.0% grade is approaching from D towards C, descending the 0.6% grade; on reaching C the train (provided there are no stops) will have acquired a certain momentum, due to the velocity acquired by its fall from D to C, plus the use of its own power, which momentum will allow the train to run a certain distance

on a level grade beyond C, as CE, without using any further power from the locomotive, or run a certain lesser distance on an ascending grade, which lesser distance is directly proportional to the rate of grade, or, provided proper devices could be provided, this same momentum or stored energy could be made to lift the train a certain number of feet vertically at the point C.

The engine, then, being assumed to be capable of hauling the train (in this case) over the 1.0% grade, the momentum can be utilized to overcome the resistance due to the other 0.5%, and the question to be solved is: how long can the 1.5% grade be?

On the level grade the acquired momentum would be used up entirely in overcoming the resistance of the train itself; on the ascending grade it would be used partly to overcome the resistance and partly to overcome the vertical lift.

The amount of stored energy or momentum in the train when it arrives at C is, of course, in direct proportion to its speed, and could be very closely calculated were every train alike; but the differences in rolling stock, composition of the train, etc., introduce variations in the train resistances (that is, in the resistances due to friction of bearings, etc., other than the resistance due to the weight of the train) which require certain broad assumptions. Making these assumptions from the averages of experiments, the late A. M. Wellington calculated a table from which Table 1 has been condensed, showing the number of feet in height through which a train will be lifted by its momentum (after making due allowance for the internal resistances), at various speeds from 10 to 50 miles per hour, and which height he has called the *Velocity Head*.

TABLE 1.

Velocity Heads.

Condensed from Wellington's Economic Theory, Page 335.

Miles per hr.	V. hd., in ft.	Miles per hr.	V. hd., in ft.	Miles per hr.	V. hd., in ft.	Miles per hr.	V. hd., in ft.
10	3.55	20	14.20	30	31.95	40	56.80
11	4.30	21	15.67	31	34.12	41	59.68
12	5.11	22	17.19	32	36.35	42	62.62
13	6.00	23	18.79	33	38.66	43	65.64
14	6.96	24	20.46	34	41.04	44	68.73
15	7.99	25	22.20	35	43.49	45	71.89
16	9.09	26	24.00	36	46.01	46	75.12
17	10.26	27	25.88	37	48.60	47	78.42
18	11.50	28	27.83	38	51.26	48	81.79
19	12.82	29	29.86	39	54.00	49	85.24

Thus, in the case assumed, if the train from D to C approaches C at a speed of 25 miles per hour, it is found, from the table, that the energy stored in the train will lift it through a vertical height of 22.2 feet, 1.0% being the ruling grade, the engine will be supposed to take care of that, the remaining 0.5% being overcome by the momentum; and since this will lift the train 22.2 feet, the length of the 1.5% grade may be $22.2 \div 0.5 = 44.4$ stations. It is desirable, however, that the train should have a reserve energy on approaching the 1.0% grade equal to a velocity of not less than 10 miles per hour, which (from the table) is equal to a vertical height of 3.55 feet; deducting this from 22.2 leaves 18.65 feet, which divided by 0.5 gives 37.3 stations as the permissible length of the 1.5% grade.

As it is always desirable, as far as the exigencies of the service will permit, to load each engine to its maximum capacity, this often means that, while the loads may be proportioned to the ability of the engine to haul them over the ruling grades, they are often greater than the same engine can start from a standing stop on the same grade; 10 miles per hour being considered the lowest economic speed of freight trains, this allowance is made, and the length of the heavier grade limited so that the speed of the train will at no point be reduced below this. Some margin also must be allowed for the state of the track and condition of rolling stock, either or both of which may be in a much lower state of efficiency (consequently increasing the resistances) than had been used as a basis for the calculations.

Mr. Wellington's table is based on a resistance due to rolling friction of 7 lbs. per ton, Webb's handbook assumes 10 lbs. per ton, and recent experiments on long, heavy freight trains* seem to show resistances as low as 3 or 4 lbs.; for old-established lines, where all stops may be assumed to be permanently fixed and where all conditions are fairly well known, a low assumption may be justified, but on new construction it will probably be only safe to figure on half the length of a grade of this kind shown by the table, or, in other words, assume that the momentum will only lift the train half the height given in the table. In cold climates, too, allowance must be made for the fact, if necessary, that the resistances of the bearings are greatly increased by the

*Trans. Am. Soc. C. E., Vol. L., p. 1.

low temperatures, especially where trains have stood any length of time, and the total resistance of the train considerably increased until it has run a sufficient distance to get the bearings warmed up.

In any event maximum grades higher than the ruling grade should be introduced with much caution. Considerable differences of opinion exist even among some of the most prominent railroad engineers as to the advisability of using momentum grades at all. On very busy roads the stalling of one train might cost more than the amount necessary to reduce the grade; on the other hand, an intelligent and conservative use of momentum grades might save considerable on the cost of construction, and sometimes permit of a lower ruling grade.

The fact that a somewhat high rate of speed is necessary in approaching them limits their use to places where there will be no stops or any necessity of slackening speed. Stations, water-tanks, or sidings, on the approach, absolutely prohibit their use, and sharp curvature or grade crossings, necessitating low speed, must be considered in assuming the rate of speed of the approaching train. The probable location of a water tank in a sag in the future is a possibility which should always be kept in mind, as this might involve a stop, which would, of course, destroy all the effect of the momentum.

Curvature on the maximum grade when this is greater than the ruling grade, must, of course, be compensated the same as elsewhere, though probably a little more liberally, and in calculating the length of the momentum grades the entire resistance of the curvature must be taken into consideration.

On new construction these grades may be sparingly introduced to cheapen construction, particularly in places where they may be afterwards eliminated; but the writer would advocate taking not over 50% of the heights given in the second column of Table 1 in any place.

The speed of freight trains, which are those usually only to be considered in this connection, should usually not be assumed greater than 30 miles per hour at any point on new roads.

Two maximum grades greater than the ruling grade should not be introduced on opposite sides of the same sag, nor even one maximum grade greater than the ruling grade on one side, with a

stretch of ruling grade on the other, as in such a case a train which failed at the first trial to surmount the steeper grade owing to lack of sufficient momentum would be stalled in the depression until another engine could be obtained to help it out, or while it took part of the load ahead to a siding, in either event blocking the line.

It has been stated that slight undulations of the grade line involve very little extra cost of operating. This will be understood by referring to the previous paragraphs on virtual grades, and Table 1. For instance, in Fig. 43, suppose the grades A B, F G are level and at the same elevation, a train approaches B at 25 miles per hour; it has then, according to Table 1, a "velocity head" of 22.2 feet; if the fall vertically from B to C be 21.29 feet, the velocity head will be increased by that amount (provided the engine exerts the same pull all the time) by the time the train reaches C, a total of 43.49 feet, equal to a speed

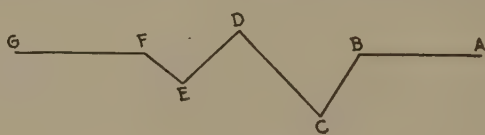


FIG. 43.

of 35 miles per hour, which will be the speed of the train at C; the elevation of D above C being 29.29 feet, the velocity head at D will be reduced to 43.49 — 29.29 = 14.20, equal to a speed of 20 miles per hour; descending to E, a vertical drop of 17.75 increases the velocity head by this amount, 14.20 + 17.75 = 31.95, giving a speed of 30 miles per hour at E. F then, being at the same elevation as B, the vertical height from E to F will be 9.75, which, deducted from the velocity head at E, 31.95, leaves a velocity head at F of 22.20, equal to a speed of 25 miles per hour, showing theoretically that the undulations of the grade between B and F have no effect on the operation of the road other than a straight grade between these points; all this, irrespective of the rates of grade, the engine being supposed to exert continuously just sufficient power to haul the train on the straight grade, the *virtual* grade line, therefore, between B and F being theoretically a level grade.

In such a case as noted above, if the depth of any sag is such

that the highest permissible speed of the train would be exceeded at the low points, this must be taken into consideration, as, for example, a speed of 35 miles per hour is shown at C, which is rather in excess of what is usually considered safe for freight trains, 30 miles per hour being generally considered the safe limit. In this case, brakes would have to be applied or steam shut off to reduce the speed within the safe limits, and the speed of the train, provided the same power was exerted by the engine for all the rest of the way, would be reduced at all points beyond C 5 miles per hour, or the engine would have to exert the extra power necessary to increase the speed, or, in other words, if brakes are applied to reduce the speed 5 miles per hour, this uses up the momentum which would have lifted the train 1.8 ft. vertically, and the engine will have to exert the power to do this work which would otherwise have been accomplished by the momentum, and therefore at a speed of 30 miles per hour the undulations fail of being surmounted by the momentum of the train by the power necessary to lift the train 1.8 feet vertically—in other words, there is 1.8 feet of rise and fall to overcome.

If stops are necessary, or speed has to be reduced for sharp curvature, momentum is lost of course in the same way, wholly in the first case and partially in the latter.

The whole point of this discussion of momentum grades is, *that within certain limits,* which are more or less wide at present, owing to differences of operating conditions, lack of data and differences of opinion as to the value of the data we have, undulating grades do not increase the cost of operating, and that in the case cited, provided a speed of 35 miles per hour is permissible, and we adopt the full values given in Table 1, the undulating grade line between B and F will cost no more to operate than a straight grade between the same points.

In actual practice the objection to an undulating grade, even when theoretically it is well within the limits where extra work will not be required of the engine, is the abrupt changes of speed, even where the grades are connected with easy vertical curves, resulting in much wear and tear on the draft rigging, of the cars, breaking and pulling out of draw-bar heads, and sometimes the crushing of a weak car in the middle of a train at the bottom of a sag.

Whilst theory would permit the use of undulating grades of any rate and any depth within the limits noted as far as any effect on the demand on the engine is concerned, actual practice in operation interposes many objections, and it will be well, therefore, to keep well within the limit of 50% of the values of Table 1 recommended above, unless in the case of operated roads reliable data is to be obtained, justifying higher values. With this, as with other theories, as an actual fact it will be found in practice that, whilst some knowledge of the economics of railroad location, that is, the values to be given to curvature, rise and fall, length of line, and the effect of increase or decrease in the ruling grade, etc., is very necessary, it is more often the case that the complications arising from the necessity of avoiding a bad river crossing, a heavy rock cut, or of reaching some particular point of control, and the thousand and one other things which control the location, will overshadow the economic theory, and the fixing of the grade line will more often be controlled by topographical than other considerations. The great point is that the locating engineer must never lose sight of the fact that the road has to be operated, and the largest possible profit made on the outlay, and he must have some practical knowledge of operation himself, as well as of the methods of location, and a good equipment of common sense, to strike a proper balance between theory and practice and the necessities of the topography. Practice, the result of observation and experience, must go hand in hand with enough theory to prevent those costly errors which have been made as the result of ignorance or neglect of the necessities of operation. The values of curvature and rise and fall are further discussed in Chap. VIII in connection with estimates of cost, etc.

Staking Out the Located Line.—In staking out on the ground the located line as finally determined and projected on the map, it is obvious, of course, that, provided the preliminary lines have been accurately run, that is, accurately solely from the surveyor's standpoint, and that they have been accurately platted, it is simply a matter for mathematical calculation and accurate surveying to reproduce on the ground a line having the same relation there to the preliminary lines as it does to these lines on the map, in fact, a somewhat elaborate treatise recently appeared in one of the engineering periodicals giving elaborate formulae and methods of calculation for such a procedure.

It should be obvious, however, from the previous discussion, that the author does not consider that the time and expense necessary for such accuracy in the measurements, etc., of the preliminary lines, or of the topography hung on them, is warranted, the same results, as far as getting the location on the ground in its proper place being obtainable by other means at far less cost.

Staking out a line by such mechanical methods also involves the liability to errors due to what is practically enlarging the scale of the map to full size, and makes no provision for elasticity in fitting the line to the ground, as noted hereafter.

It should be carefully noted and understood that there is absolutely no particular virtue in getting a line on the ground which bears some particular prearranged geographical relation to some other line; but what *is* required is to get a line staked out which is in itself—*the best location*—regardless of its relation to the preliminary. The writer wishes to emphasize the point that, having made our topographical map generally correct, we have developed the general features of the best line, and that our aim must be to see that the line on the ground conforms to and reproduces these general conditions, and the fact that in ordinary country a line is two or three or often even ten feet one way or the other has little effect on it, as the grade line has to be adjusted to whatever profile is obtained. On steep side hills, under certain conditions (generally when running a grade line and where the grade is fixed), it is necessary that the line should be in a particular place on the ground, but this is always a place having a fixed relation to the height or elevation of the ground and not to the preliminary line. The all-important point is to get the final line in its proper position on the ground to produce the results which we have previously determined to be the best.

It is here that the method of making a projected location differs widely from the old so-called "paper location," which is generally referred to, and rightly so, by many of the older locating engineers, as well as the newer ones, with a certain accent of depreciation, inasmuch as a paper location has been, and is, too often, a line projected on a map with little or no other information than a bare preliminary line hastily run, and a few inadequate

notes, and which projected line, even from a careful preliminary, in all probability would bear little resemblance to the line finally developed on the ground, either in plan or profile, and estimates made from such a line would probably be misleading, as estimates generally are which are based only partly on accurate data, or insufficient data, and partly on a guess, and will be nowhere near as good as the guess of the "practical" man riding over the ground and simply looking at it.

Between the two extremes of unnecessary accuracy and elaboration in map making and the old so-called "paper location" the true method lies.

In what follows in this chapter it will be assumed that the preliminary lines are such as are ordinarily run, and the topography generally correct (see pages 68 to 70). It should then be possible to reproduce on the ground a line which will be substantially the same as that projected, and a profile of it should show up generally the same as that previously obtained from the map. That this is possible has been proven time and time again, not only by the author, but by many others. (For modifications and special surveys, see Chapters VII. and IX.)

In taking from the plan the notes necessary for the establishment of the line on the ground, the locating engineer should explain carefully to his assistant what are the most important points to be taken care of, or avoided, in establishing each tangent, where the line must clearly conform to certain conditions and where it may vary and within what limits, the keynote of success in the whole thing is an intelligent appreciation by all concerned, not only of what they are doing, but why; and in laying out the location on the ground not simply blindly reproducing a certain line from the map, but obtaining certain final results.

Each tangent should be established on the ground, run to an intersection, or the P. I. calculated where inaccessible, and the P. C. and P. T. of each curve set, before the curve is run in. Some objection was made to this in the discussion of the writer's paper, but he would insist most emphatically that this should be done, and on no account should a curve be started at one end and run around before the both ends have been set by calculation.

Where speed is an object, and the country allows, a separate

party may be sent ahead to block out the tangents—simply establishing the necessary transit points—the main party following and measuring the line, driving a stake at every station and running in the curves. Where a long stretch of location has to be run in this extra transit party is often an economy, as by blocking out the tangents the second party makes greater progress, keeping the leveller busy and distributing costs of supervision, cooks, teamsters, etc., over a larger amount of work, and the extra party can often be employed to advantage running extra preliminary lines to further develop some short stretch which may seem to require it. For this and for many other reasons it is advisable to have an extra transit with the party. It is often advisable to set stakes oftener than at each station of 100 feet, where the country is such that cross-sections will be required at intermediate points, and especially so where the location is to be followed

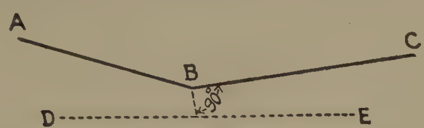


FIG. 44.

immediately by construction; on curves over 4° stakes should always be set at least every 50 feet.

In the simplest case of laying out a line on the ground from the projected location, in open country, where there are no particularly long tangents, probably all that will be necessary will be to scale from the map distances from some of the hubs on the preliminary lines to the projected tangent, and measuring in these distances on the ground establish three or four points which should line in fairly well; points (hubs with tacks) are then definitely established on an average line through the points obtained by measuring out, and the line thus fixed.

Usually, all distances should be measured only from the hubs on the preliminary and not from intermediate stakes, and at right angles to the preliminary line.

If the hub is at an angle point, as at B (Fig. 44), the distance should be scaled and measured from B to the line DE (the proposed location), perpendicular to BC. It is seldom advisable to scale the distance perpendicular to the pro-

jected line, as when the measurement is made in the field the projected line will not exist. The scaled and measured distance also should be perpendicular to that part of the preliminary nearest parallel to the projected location, thus in this case to B C rather than to A B.

It is sometimes necessary or desirable to establish points by measurements from intermediate stakes, in which case these should be checked from the hubs on either side before being used.

It is obvious, of course, that in scaling distances from a map 400 or 200 feet to the inch, the nearest two or three feet is the best that can be done, and that where two or more distances are scaled and laid out, as there always should be, they will seldom line in exactly; but in country where it is possible to establish the line wholly by horizontal measurements from the preliminary, 3 or 4 feet difference seldom seriously affects the line, and an average must be taken of the points laid out.

There are times when artificial topographical considerations, such as land lines, buildings, etc., establish certain points on the location. These must be noted from the map, and due consideration given them in establishing the line, as also to such natural topography as high bluffs, stream crossings, etc.

It is in laying out the projected location on the ground that the whole success of the methods advocated lies; if the man who lays out the line is a machine, he must have a perfectly accurate survey and map to work from, and even then will fail; if he uses common sense and judgment, only sufficient accuracy is necessary on the preliminary work so that the studies made on the map show correct results within the limits of the scale used, which will seldom be larger than 400 feet to the inch. Any line located is a compromise between many different factors, and while it may seem a broad statement to say that 3 or 4 or even 10 feet makes little difference, it is only necessary to take a piece of thread and attempt to move it a distance equal to only, say, 5 feet, on a map 400 feet to the inch, to see what a very little difference it makes, besides which there is always the adjustment of the grade line to follow, on any line laid out.

It is at this point that those who have favored the so-called "field location" claim the superiority of their method, that the

line can be fitted to the ground more closely in the field than on a map.

The fallacy of this must be evident if the writer has succeeded in any measure in explaining his position; the best line has been projected on the map, conforming to all conditions, as far as the scale will allow, a more or less small scale being necessary that the locator may grasp the whole general situation; then, knowing what the general results should be, and really, as a matter of fact, fairly close details—he can go on the ground and locate his line, knowing that it is generally correct, but adjusting it to any of the smaller details of the topography with a far better appreciation of their true value and effect than the man who has only seen them on the ground. The location of a line on the ground without the aid of the map simply means even with a skillful man that it fits the details perhaps fairly closely, as far as the man can see on the ground, but ignores the general broad considerations which should properly govern the whole location.

It is then clear that mere mechanical accuracy of preliminary lines and topography will not in themselves produce a good line, nor will small inaccuracies within the limits of the scale vitiate it; common sense, experience and good judgment must be brought to bear in laying out the location on the ground, equalizing any of the small errors of topography and of the preliminary lines.

Long tangents in wooded country are somewhat difficult to establish, especially if tied down closely to some particular point at or near each end; usually, however, in country permitting long tangents a variation in their position of 10 or even 20 ft. has very little effect; each particular case, however, must be judged on its own merits, and, if necessary, the preliminary lines run with sufficient accuracy to permit of the calculation, generally by latitudes and departures, of its relation to the projected line.

In wooded country, where it is very expensive to chop out a line, and it is therefore necessary that the line be established correctly the first time, if it has not been thought desirable to run the preliminary line or lines with any more than the ordinary degree of accuracy in the first place, the line most closely approaching the location, if there be more than one preliminary, may be remeasured with sufficient accuracy, both as to distance and angles, to allow of the location being calculated; the writer has

never, however, found this necessary in his own practice. In one case, on a tangent about two miles long (O S, Fig. 45), both ends were fixed within about 5 ft. opposite A and E, the actual length between these points being 97 stations. The stations on the preliminary line, A B C D E, of the points X and Y, were scaled from the map, the angle C being known, the remaining angles C X Y and C Y X were calcuated, the distances at A, B, D, and E perpendicular to the line O S were scaled and noted and the station of the point Z. On the ground the point X was carefully established and a hub set, the angle C X Y turned, the perpendicular distance at B checked and clearing started towards Y and continued about half way. The point Y was then established, the angle C Y X turned and clearing started towards X; the lines varied where they met about two-tenths of a foot. A line was then established which passed nearly through X and Y

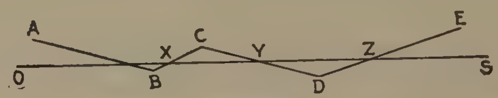


FIG. 45.

and produced towards S, checks were made at the point opposite D and at Z, which, being satisfactory, the line was continued to S, varying little from the distance scaled from E; the line was then run back to O, and being found to be on the right ground there intersected with the tangent behind, the preliminaries having been run with only the ordinary care.

Care should be taken when getting the notes from the map to get sufficient, that plenty of checks may be obtained before the line has been run too far, and to see that the points to be established will be in such positions that they can be used to advantage; more than one means of establishing the line should be studied, as unforeseen obstructions often prevent the utilization of some point or points selected.

In mountainous country, where curves predominate, a number of points should be established on the ground by vertical distances from points on the preliminary, and the line passed through them, so that the profile determined beforehand to be the one we want will be obtained. Notes are taken from the map

and profile of the projected line, of what the required elevation of the ground will be at important critical points; and from the level notes, of the elevation of some easily identified point on the preliminary; then with the hand level the points can be established on the ground at the required elevation opposite certain points on the preliminary, and the line, whether curve or tangent, passed through these points, or close enough to them so that there will be no material difference in the profile.

This method of establishing points on the ground by vertical distances is one which should be carefully borne in mind and used far more frequently than it is, especially in any place where the grade line is practically fixed, and the location depends for its position more on the elevation of the ground than on anything else; in country permitting long tangents the fact, as previously noted, that the line is 10 ft. one way or the other, seldom makes much difference, as the grade line can almost always be adjusted to fit the profile.

A section of the projected profile, covering the work in hand, should be taken into the field, and at critical points, the profile as obtained by the leveller, platted there, so that any discrepancies may be at once seen and the line changed, if necessary, to remedy them before being pushed ahead; if this is done, equalization stations, as the result of revisions after the location has been carried forward some distance, can be avoided to a very great extent.

All of the field work on location must, of course, be done much more carefully than on the preliminary lines; each stake should be lined in so that the line falls on it, but it is seldom necessary to make a mark exactly on line. The measurement should be checked after the stake is driven and a mark made at the exact distance. All curve computations, including the deflections for each station, should be made by the transitman, be checked by some other member of the party and entered in the note book before the curve is run in; a line may be left between each station to allow for the insertion of plusses.

A good plan, after calculating the deflection for the first even station after the P. C., is to add to it continuously the deflection for each full station, then calculate the deflection for the plus to the P. T., and add that, which should give a total equal to half

the deflection angle. The computations for the curve, as shown (Fig. 46), are given in detail below:

Deflection angle as observed, 10° 28′.
2° Curve.

To Get S. T.	To Get L. C.
Nat. tan of 5° 14′ = .09159.	10°—28′ = 10.4666°, which, divided
Rad. 2° curve = 2864.93.	by 2 (the degree of curve), gives
2864.93 × .09159 = 262.40 = S. T.	5.2333 Stations = 523.33 ft.

The length of S T is then measured in both directions from the P. I. and hubs set, the Sta. of the P. C. is then found by measurement from Sta. 733 to be 733 + 14.61, or if the measurement has already been carried up to the P. I., and that point had been found to be 735 + 77.01, 262.40 would be subtracted from that, and the station of the P. C. found to be 733 + 14.61, and the hub for the P. C. set accordingly at that station from Sta. 733 by measuring 14.61.

Having found the station of the P. C., the next thing is to calculate the deflections; that for the first even station, 734 is for a distance of 85.39 ft., and, of course, is $\frac{85.39}{100}$ of the deflection angle for 100 ft., which latter is half the degree of curve; in this case for a 2° curve = 1°. So the deflection for 85.39 ft. is $\frac{85.39}{100}$ of 1°.

$$\begin{array}{r} .8539 \\ 60 \\ \hline 51.2340 \\ 60 \\ \hline 14.0400 \end{array}$$

= 51′—14″.
First deflection.

Sta. of P. T. will be:

$$\begin{array}{rr} & 733 + 14.61 \\ + \text{L. C.} = & 5 + 23.33 \\ \hline & 738 + 37.94 = \text{P. T.} \end{array}$$

Deflections for Stations.

734	51′ 14″	
5	1° 51′ 14″	Adding 1° each time for each whole station.
6	2° 51′ 14″	
7	3° 51′ 14″	
8	4° 51′ 14″	
	22′ 46″	deflection for 37.94
8 + 37.94	5° 14′ 00″	= half central angle.

Deflection for last plus 37.94.

$$\begin{array}{r} .3704 \\ 60 \\ \hline 22.7640 \\ 60 \\ \hline 45.8400 \end{array}$$

= 22′ 46″

In cases where it is necessary to set an intermediate transit

point on the curve, as in this case at 736, the rule for the deflection is that *the vernier must always read the angle of the station sighted at,* whether it be backsight or foresight.

Thus, for instance, if the instrument is at 736 and a backsight is given on 733 + 14.61, the vernier must read zero on the backsight; then to set 737 the telescope is revolved in altitude (or turned through 180°) and the angle for 737 will be 3° 51′ 14″. Similarly, if the instrument is at 736 and a backsight is to be obtained from 734, the vernier must be set at 0° 51′ 14″ (on the correct side of the zero, as the curve may be to the right or left), before sighting at this station, then the telescope set on the backsight; then to set station as 737 the angle will be 3° 51′ 14″, as before. Similarly, if the curve is being run backwards, if the instrument is at 735 and a backsight is given at 728, the vernier is set at 4° 51′ 14″ (the deflection for 738); then the backsight taken, and to set, say, 733 + 14.61, the P. C., the vernier is turned back to 0, the deflection corresponding to that station. The station over which the instrument is set makes absolutely no difference, the vernier reading for all sights must correspond to the station *sighted at.* In calculating the deflection for any intermediate plus, the calculation is made, of course, for the odd distance from the even station behind, and added to the deflection for that station.

If, for instance, it was necessary to set a point at 735 + 20, the deflection for 20 feet is 20/100 of 1° = 12 min., which, added to the deflection for 735, which is 1° 51′ 14″, gives 2° 03′ 14″, the deflection for 735 + 20.

After a curve has been run around, the angle from the last visible hub on the curve, to the tangent should be checked, as for instance, in the curve given, the instrument being set up at 738 + 37.94, the vernier is set at 2° 51′ 14″, corresponding to station 736, and a sight being obtained on this station, the telescope turned to the line of the tangent, the vernier should then read 5° 14′ if the work is correct.

As noted previously, the stakes used on location must be good, substantial stakes (oak or chestnut. if possible), blazed on both sides so that cut or fill can be marked on the back later.

Careful notes should always be insisted on, and the chief of party should see that they are kept in a proper manner; impress-

Sta	Dist	Defl	Course	Cal. Course	
7		2.42.43			
6		1.12.43			
755+19.21	P.C. 3°	L			
751+38					
748+25					
743+20					
742					
	1681.27		N 42.30 E	N 42.46 E	
738+37.94		5° 14′ 00″			
8		4.51.14	∠	10° 28′	
7		3.51.14	Rad	2864.93	
6		2.51.14	S.T.	262.40	
5		1.51.14	L.C.	523.33	
4	523.33	0.51.14			
733+14.61	P.C. 2°	R.			
729+50					
723					
	1276.40		N 32.10 E	N 32.16 E	
720+38.21					

FIG. 46.—FORM OF LOCATION TRANSIT NOTES.

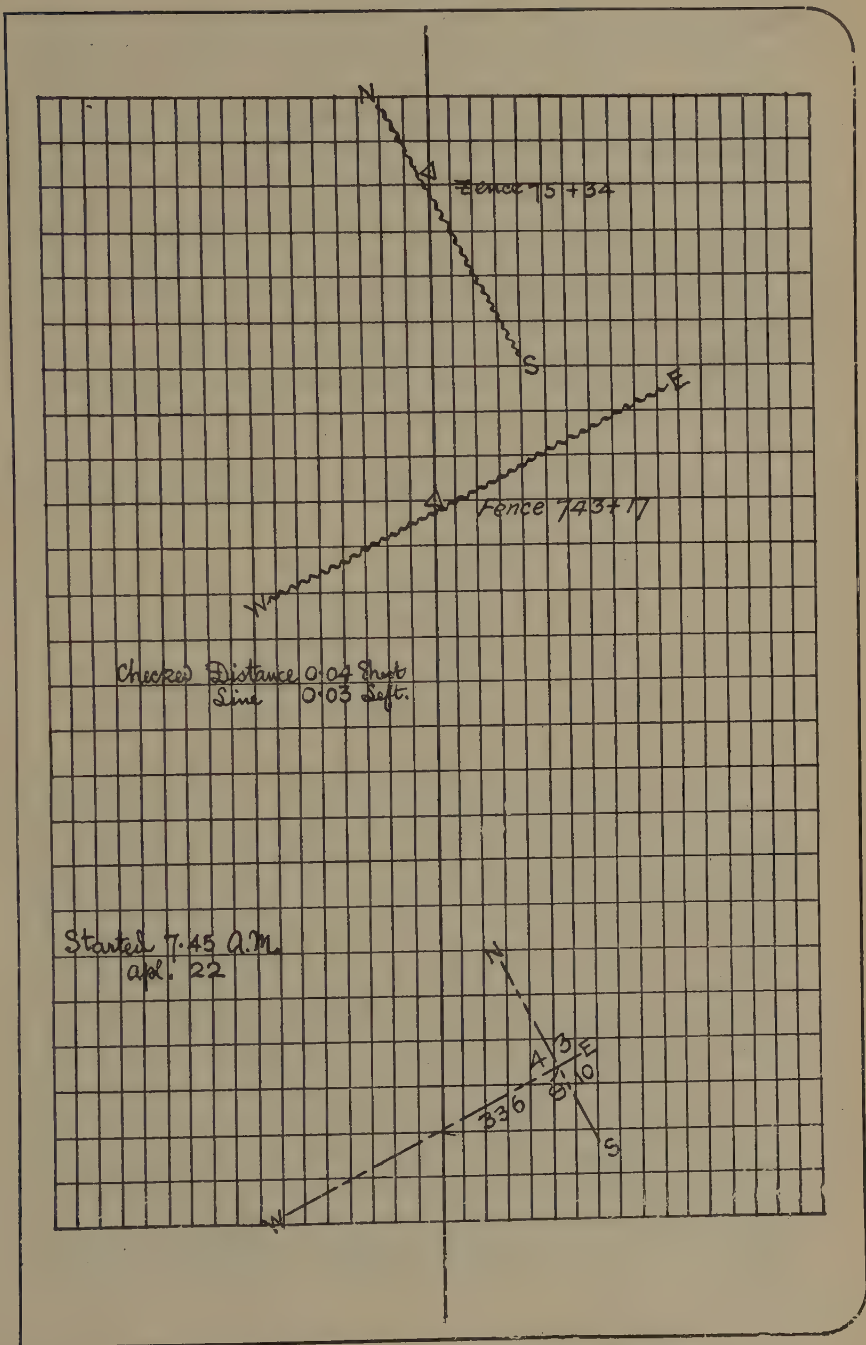


FIG. 46.—FORM OF LOCATION TRANSIT NOTES.

ing on each man the necessity of keeping his notes so that they are always made immediately, at the time they are taken, not left for some dim and distant future, and in such a manner that they can be readily understood by an entire stranger ten years hence if necessary.

In starting a location from an existing railroad, establish the frog point so that it can be put in at a rail joint and so that only one rail will have to be cut.

Establish the point of frog about 4 ft. from the joint either way, turn off the frog angle from the rail in which it is to be placed and establish the center line of the new location half the width of the gauge from and parallel to the line thus obtained.

The general form of transit notes for location is shown in Fig. 46.

Great care should be exercised to note the equality stations

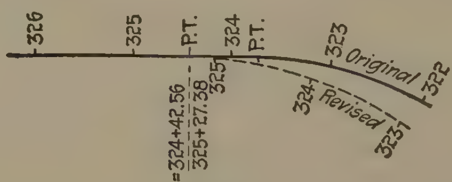


FIG. 47.

clearly; thus, if the revised line is longer than the original, if, for instance, the end of the revision is at 324 + 42.56 of the original, and 325 + 27.38 on the revision, these stations should always be shown everywhere in the order in which they occur on the ground when starting from 0. Thus, in the notes, they will show as follows:

Transit, Reading up from the bottom.	Level Notes, Reading down from the top.
326	323
325	324
= 324 + 42.56	325
325 + 27.38	325 + 27.38
325	= 324 + 42.56
324	325
323	326

They will be shown on the map as in Fig. 47, and on the profile as shown in Fig. 48.

Frequent ties to the preliminary should be obtained, so that the final line as staked out can be drawn on the map in its proper re-

lation to what is already there and then inked in, the projected location having previously been kept in pencil.

Spirals should be allowed for by offsetting the curves the proper distances, on all curves over 3°, but the spirals themselves need not be run in, that usually being left for the construction party.

Land Lines.—Where land lines are infrequent they may be taken by the transit party in passing. The head chainman will get the plus and record it *at the time* in a proper note book, and where necessary on closely defined lines a hub should be driven, so that the transitman can get the angle. In country laid out by the United States Government Land Survey the section lines should be carefully run out, intersected, and angles and plusses

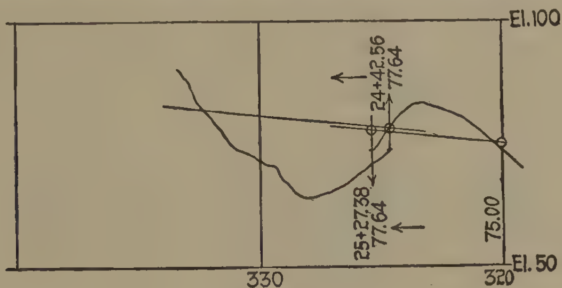


FIG. 48.

measured. Where the land lines are sufficiently numerous, a separate party of about three or four men should be organized to get them, as it causes unnecessary delay to a large number of men to have the main party stop for this work, or the transit party can be broken up into two or more parties and get them later. This is one of the many cases where a second transit can be used to advantage.

Sufficient information should be obtained so that the whole, or at least enough of each piece of property, of which part is taken, can be shown on the map (Fig. 49), so that the effect of the taking on the remainder of the property can be readily seen.

Where the reconnaissances and preliminaries have all been completed before the location is run in, there is no reason why the locating engineer should not actually take charge of the party in the field, at least part of the time, and, where possible, this is to

be preferred, leaving the assistant to take the land lines, drainage areas, etc.

Where soundings are taken, as they always should be, the topographer can look after this work, two or three laborers being engaged to help him, and the depth to the top of the rock where there is any, determined quite closely and some idea obtained of the character of the materials overlying it. The writer has generally used an ordinary ship auger, welded to a long iron rod, somewhat smaller than the auger, with an adjustable handle. Care and judgment of course, must be taken in using the results

FIG. 49.—RIGHT-OF-WAY MAP. SCALE OF ORIGINAL, 200 FT. TO THE INCH.

of such soundings that too much dependence be not put on them, but soundings of this kind give a much better basis for an estimate than mere guesswork and are worth much more than they cost.

When the profile of the final location has been platted, a temporary grade line should be laid on it, and drawn lightly in pencil, the results of the soundings noted, and the profile then taken into the field by the locating engineer, who should then go over the line on foot, carefully noting any points which may affect the final determination of the grade line, the sizes and loca-

tions of all openings for waterways, extra right of way for slopes, borrow pits, etc., steep side hills especially.

This last final study of the line on the ground with the profile in hand should be strongly insisted on, as many details will be noticed then which can only be seen that way and which may have previously escaped observation, but which probably will have a considerable effect on the cost of construction.

It is usually the case that the location, as made by the engineer in the field, is subject to revision by some higher authority. It is highly important therefore that any method adopted for the surveys should offer every facility for this review. Many roads, especially in the West, where new projects and extensions of the larger systems are constantly being investigated, keep several fully equipped locating parties in the field at all times, and where a line is of sufficient length enough parties are placed on it so that the work can be done and a report made on the whole project without too much delay. The methods herein advocated permit very readily of some one higher in authority than the chief of the party following the whole process of the location step by step; the ground can be looked over before the location is made, the projected location criticised and the whole scheme discussed step by step before the final location is staked out, by whoever is finally responsible for the surveys. On the C. O. & G. R. R., where often as many as eight or ten locating parties were in the field at one time, this work was under the immediate general direction of the principal assistant engineer. He visited each party from time to time in the field, criticised where necessary, the work of each, and co-ordinated the work of all parties where more than one was working on the same line. A much more intelligent appreciation or criticism of these lines was thus possible than where a map has been platted, showing only the bare preliminary lines and the final location, and an attempt is made to size up the country and the relation of the located line to it by the final reviewing authority, or where, as is quite often the case, the line has been simply looked over on the ground by the reviewing authority after it is staked out.

It may be and has been said that this relegates the locating engineer to a secondary position. This is perhaps true, but really is so in any event. It is very seldom that the chief engineer of a

railroad of any importance makes his own location, but if he has the proper idea of the importance of it he will seldom care to delegate the whole responsibility to such men as are usually to be found in actual charge of the party in the field. They should be, and must be, men of intelligence and experience, and the position has plenty of dignity of its own, but there is generally some one higher up who is finally responsible, and methods should certainly be adopted so that the man who makes the final review should be able to do so intelligently, and not have to depend entirely on what the chief of the party is able to tell him of what he has seen or thinks he has seen on the ground, which has influenced the location, but which is not recorded anywhere but in his own impressions.

The grade line on the final profile should especially be left for final review. In fact, in one instance, the writer knew of a chief engineer who insisted on fixing the grades himself, although in many instances he had neither seen the line on the ground nor the map. After the study of the located line on the ground, with the tentative grade line, and after the openings have been carefully fixed and their character decided on, and results of soundings all noted, the tentative grade line should be carefully gone over and revised before the final estimate is made, and when satisfactory, left in pencil, so that any small revisions suggested by the reviewing authority may be made, and then finally inked in.

It will be found by actual experience, and a little closer study perhaps, that the grade line can always be fixed so that it is seldom necessary to use more than one decimal place, in either the rate per cent. or the elevations of the grade points, and this saves much time on construction, and ever after, and with grades up to 1.0% it should never be necessary to break the grade at anything but the even stations. Compensation for curves should be from the nearest even station to the ends, and where spirals or easements are introduced this may generally be from the ends of the true curve (that is, the true curve from the offset points, including the whole central angle), except where the spirals may be very long, and then an average rate for the spiral may be introduced.

The whole of the office work, location profile, both original and tracing, right of way map, estimate of quantities, etc., should

be kept closely up to date, and should never be more than two or three days behind the staking out of the line, so that blue prints of the profile tracing, and the 5,000-ft. map, as well as schedules of approximate total quantities, can be made at once and given out to contractors who may wish to look over the work and bid on it; and with the information on the maps and profiles as previously described and indicated (Figs. 25 and 27), their bids can be made on an intelligent basis and fairly accurate knowledge of the conditions, and will therefore probably be lower than where such bids are made on many uncertain factors.

CHAPTER VII.

SUBURBAN RAPID TRANSIT RAILWAYS.

Surveys for the location of railroads in the vicinity of large cities involve problems in many respects very different from those encountered in the more thinly populated sections of the country; the large number of streets to be crossed and the necessity of avoiding grade crossings introducing complications not usually found on ordinary location.

In the vicinity of New York, recently, various projects have been developed, and construction started on some, for high speed electric railways, in some cases providing for four tracks, on their own right of way, designed to conform in every respect to the best modern trunk line steam railroad practice in all that pertains to construction, besides the necessary electrical equipment.

The natural topography of the country, as shown by the contours, instead of being largely the controlling factor, as in ordinary location, will have comparatively little weight; the necessity of avoiding crossing streets at grade, especially where there are many of these, of avoiding expensive buildings or right of way, and of reaching the centres of population and points where the development of the country is likely to furnish the largest passenger traffic will have the greatest influence in deciding the location.

On two alternate routes, each about two miles long, which were compared in one instance by the writer, the cost of right of way was estimated to be nearly $300,000 less on one line than on the other, but the more expensive line reached the centre of the town and the other did not. It is often possible to change the grade or location of a street, and more particularly country roads, rather than to attempt to avoid them in their original location. In many instances two streets, or a railroad and a street, are so placed that it is impossible to avoid both; in going under streets of towns or cities, sewers, water and gas pipes, electrical conduits,

etc., have to be avoided or changed, thus introducing other complications. The necessity for full, accurate surveys, therefore, is very apparent, and although the natural topography has such comparatively little influence on the location, it should not be imagined that it can be at all neglected, and the contours must be located and platted on the map as well as the streets, buildings, property lines, etc.

The high speed at which it is necessary to operate these roads, their existence owing its origin solely to the demand for more rapid transit, requires good alignment, but the introduction of the multiple unit system of electrical control and operation, and the fact that these roads are designed principally for passenger or light express freight service, allows the use of quite steep gradients, grades up to 2% being in no way objectionable, and up to 3% and 4% not in any way prohibitive to the operation of passenger trains of any desired length, provided sufficient power is supplied from the central power station or the speed reduced on these sections of steeper grade.

Of course there is much the same objection to an isolated stretch of heavy grade on electrically operated lines as on those operated by steam, as extra power has to be supplied at such points in any event. In the case of steam railroads a pusher engine is required; where electricity is used, an increase in the size of the conductor is necessary between the power station and the point in question, necessitating extra wire and an increase in the size of the plant at the central station to take care of the increased load.

Where such increased grades may seem necessary or desirable near the central station, they might not be as objectionable as at points further away, although the variation of the load on the generators would still have to be given consideration.

These remarks in regard to grades apply of course only to trains operated by the multiple-unit system—generally a motor on every alternate car—which system is that used practically entirely for trains operated by electricity. Where electric locomotives are to be used heavy grades will have the same limiting effect on the weight of train hauled, as in the case of steam locomotives, the tractive force of the locomotive being the governing factor. The use of electric locomotives on the N. Y. Central and

Pennsylvania railroads, where they enter New York City, is necessitated by the fact that these locomotives replace the ordinary steam locomotives at certain points outside the city, hauling the regular through trains of Pullman and day coaches through the approach tunnels to the termini, the multiple-unit system being used even on these roads for suburban traffic.

On the approach to the New York terminal from the West in the Pennsylvania tunnels there is a stretch of 1.92% grade 3,400 ft. long, to be operated by electric locomotives; on the New York Central Railroad, on the approaches to the loop for the suburban traffic, 2.0% grades are to be used, and on the New York Subway 3% grades are operated on the approaches to the tunnel under the Harlem River, and 1.8% and 1.9% frequently at other places.

A very desirable feature on these lines, where it is possible to introduce it, is to make a hump in the grade at a station, avoiding

FIG. 50.

the use of brakes, either partially or altogether, when slowing up on approaching, and allowing rapid acceleration of speed when starting. Where express as well as local trains are handled it may be found advisable at stations where express trains do not stop to make the grade of the express track or tracks continuous, putting the hump in the local tracks only.

Some tentative scheme for handling passengers at stations should be worked out before the final location is made, as this affects the arrangement of the platforms, approaches, etc., which in turn may considerably affect the location, or at least the grade line. Where four tracks are built the arrangement is generally for two island platforms, one on either side, between the local and express tracks, as shown (Fig. 50), so that passengers may change from local to express trains, or vice versa, going in the same direction. Any arrangement of this kind, of course, necessitates overhead or underground connection between the platforms and the approaches to the station.

Where three tracks only are used, the centre track in this case being used for express service towards the centre of population

in the morning and in the other direction at night, the same arrangement can be made, with only one track between the platforms, or an island platform, to be used for express service only, can be built between the express track and either of the others, and platforms for local service outside, all being connected either by a subway underneath the track or bridge overhead, or both.

The importance of studying methods of operation and of handling passengers at stations, during the preliminary stages of the surveys cannot be too strongly emphasized, as the station layouts not only may affect the location of the line itself, but the position of the grade line, this latter most particularly. Much greater study of the grade line is necessary on a line of this kind, passing through numerous towns and cities, with a more or less dense population, where right of way is valuable and where there are many and varied interests to consider than is the case on ordinary location; in order that the quantities may be balanced, and at the same time have the grade line conform to the necessities of the various street crossings, etc. Borrow pits or spoil banks are out of the question on account of their unsightly appearance even if the cost of land for them was not prohibitive. A variation in the design of the platform or station layout in a cut or an embankment may make several thousand yards difference. If the design to be adopted is known before the final grade line is fixed this quantity may possibly be taken care of in adjustments of the grade line. Once this latter is finally fixed, however, and grades of over or under crossings determined and approved by the local or other authorities, it is practically out of the question to adjust the grade line then as might be done out in the country to accommodate afterthoughts. The character of all the materials to be excavated should be determined as closely as possible by soundings or borings during the progress of the survey, and closely studied so that the amount of swell or shrinkage can be estimated and the grade line finally adjusted to fit all the varying conditions as nearly as possible.

On the surveys of an interurban road, near New York, recently, where it was considered inadvisable to run a preliminary line across private property, lines were run through convenient streets adjacent to the proposed route, one on either side of the proposed location; these lines were connected at intervals through

the cross streets, forming a series of closed traverses, and from these lines as base lines, surveys were made covering the country between and on either side as wide as was necessary.

On account of the value of the property and the necessity of being able to project the location on the maps with such a degree of accuracy that the right of way might be bought before the line was actually run in on the ground, it was required that each traverse should close with an error of less than about 1 in 10,000. The surveys extended over a period of some six or eight months, including one or two months of extremely cold weather and running along through the summer, temperatures during the time work was being carried on in the field ranging from 25° to 100° Fahr. Measurements were taken with steel tapes, carefully compared with a standard from time to time; a spring balance was used and corrections for temperature made, all angles being repeated to insure the necessary degree of accuracy. This may be regarded as almost the extreme limit to which accuracy may be carried on location surveys, but there is probably no question that the expense incident to this work was justified by the conditions.

The whole question of accuracy is one which depends solely on the results desired, or, rather, necessary; it may have been true economy in this case to spend time and money on the surveys as described, but this outlay might in no way be justified in some other case, and certainly not in ordinary work in the open country.

In conducting a survey for a road of this kind near New York City the author used a combination of the above method with that previously described for ordinary railroad surveys. The line passed through several towns, some of considerable importance, about seven-tenths of it being in the open country, though the least valuable of the land was considered worth $3,000 per acre. In referring to towns in the following description it will be understood to mean the thickly built up parts of them.

A preliminary line was run for the whole length of the route. Through the towns the line was run through the nearest available street, running near to, and in the same direction as the proposed location; as stakes could not be driven, spikes or nails were used and driven into the macadam or joints in the paving,

the station numbers being marked on some convenient, adjacent telegraph pole, fence, or curb. Through the open country more care was exercised than would ordinarily be used, every stake being lined in so that the line came on it, and the measurement checked, and a mark for distance made on each stake after it was driven. It was not considered necessary that the distance mark should be made exactly on line. As long as both line and distance came on the stake, the measurement point could be in no case over two-tenths of a foot off line, and this would have no effect on the measurement beyond the third decimal place for distances of 10 ft., or beyond the 6th or 7th decimal place for distances of 100 ft.; for short distances, say under 20 ft., the measurements should be taken just on line.

The preliminary line through the towns was measured with great care, and all angles repeated to ensure their accuracy to the nearest 10 secs., as this portion of the line was expected to form part of a traverse which was expected to close by calculation with a limit of error of not over 1 in 5,000 of the length of the perimeter. The measurements between each transit point were usually repeated, and if the two distances checked within the limit of 1 in 10,000, using the same tape and measuring in two directions, the average of the two was taken; if they failed to agree they were repeated until a satisfactory result was obtained.

It was considered that as much accuracy as is indicated was warranted by the conditions; it was known at the beginning of the survey that it would in all probability be necessary to run several preliminary lines to properly develop all the possibilities and it was necessary that the numerous traverses which would thus be formed—that is, the traverses in the open country—should close at least within the limits of the scale of the map, which was 200 ft. to the inch. The towns were worked up separately afterwards on a scale of 50 ft. to the inch.

It was necessary also to exercise particular care with the first line, as errors in it would be difficult to detect until another line had been run, at which late date the discovery of an error in the first line would vitiate the whole map, and thus not only destroy the work of the draughtsman for several days or possibly weeks, but also delay the work of the whole survey. The necessity of

good alignment, the nature of the country and the existing railroads, all indicated the probability of long tangents, and as numerous obstructions were to be expected, the country being fairly well wooded where it was not built up, it was considered advisable to be able to calculate the relation of the projected location to the preliminary lines to facilitate laying it out; this being all the more necessary as these long tangents would be governed largely by the various street crossings, and would probably be tied down throughout their length by the necessity of avoiding some particular piece of property or in this case by the necessity of avoiding several small private cemeteries.

Considerable work in the way of getting and platting topography, both natural and artificial, was done on the first line before any of the secondary lines was run for further development; an error of any moment, therefore, in the first line, either in running it in the field or in platting it, would mean serious delay and inconvenience, and therefore expense, if it was not discovered until some other line had been run and found not to check when platted; therefore particular pains were taken to avoid large errors, as well as to keep the smaller errors within the necessary degree of accuracy.

It may be noted here in regard to calculating the relation of the projected location to the preliminary lines, that this refers only to the calculation necessary to properly block out the tangents; here, as elsewhere where long tangents predominate, the curves take care of themselves, if the tangents are in the right place; no attempt was made, as has been recently represented as feasible, to run in the whole location from one end; that is to say, after the first tangent has been established to disregard the preliminary and simply continue along, running in a line the alignment of which had been previously calculated. Each tangent must be blocked out from notes taken from the map and lie in its proper position in the country, be run to an intersection and the connecting curve put in in the usual manner.

In this connection, also, in view of the fact that from time to time it has seemed necessary to exploit special solutions of so-called difficult curve problems in the technical journals, the writer would wish to impress on the many young men who are first beginning on any curve problems, the fact that he has never yet had

occasion to use in the solution of any curve problems which he has encountered in actual railroad practice, any other mathematical knowledge than a good working acquaintance with geometry, and the ability to solve plain triangles by trigonometry, but would impress on all of them the necessity of having these at their fingers' ends and as readily available as the multiplication table.

On the preliminary lines levels were taken at all street crossings, every 50 or 100 ft. along the centre of the streets for at least 300 ft. on either side of the line, and further if it was considered likely that changes in the grade of the street would be carried beyond this distance, and these elevations were written directly on the map, the decimal point indicating the point at which the levels were taken. A very decided advantage was obtained by having these elevations written directly on the map, as a much closer adjustment of the line at street crossings could thus be obtained (see Figs. 52 and 54) than would be possible by depending on the contours alone.

Fairly good, in some instances very good maps of the various towns were obtained, principally from local surveyors, and only sufficient field work was done in the first instance to tie the adjacent street lines to the preliminary and then compile from these maps the information needed for the 200 ft. to the inch maps; any important buildings which it might be necessary or desirable to avoid were located on the ground and platted directly, as was also any information necessary in order to bring the maps up to date. Outside of the towns all land lines and buildings, as well as contours, were located on the ground, 300 ft. on either side of the line, and platted.

Through some of the smaller towns, especially in one instance where the long blocks ran at right angles, more or less, to the direction of the line, and where there was considerable space between the houses, the preliminary lines were run as close as possible to where the final location was expected to be, great care being taken in going across lots to do no damage and not to leave unsightly stakes sticking up in a man's front yard, or any stakes sticking up in drives, walks or roadways, where an animal or person might stumble over them and receive injury.

The natural topography through the open country was obtained in the usual manner, the contours being located directly

from the centre line. Where a street system had been laid out, however, the following method was found to be sufficiently accurate and allowed rapid prosecution of the work. Levels were run over all the streets on the centre of the roadway, and the elevations platted at their exact location on the 200 ft. map. A tracing was then made (Fig. 51), showing the streets, the elevations, fence lines and buildings, which tracing was then tacked on to a piece of stiff heavy cardboard and taken into the field, where the contours were sketched in directly on it, their location being obtained by pacing and hand level only. In this way the ground can be covered very rapidly by one man, and with sufficient accuracy, so that the projected profile of the line between

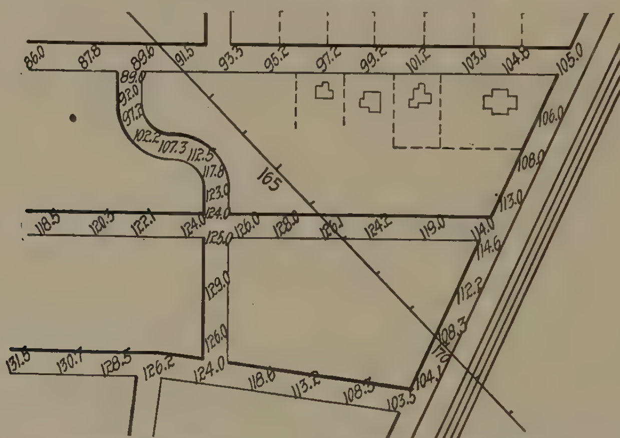


FIG. 51.—SHOWING ELEVATION PLATTED ON STREETS READY FOR INTERPOLATION OF CONTOUR.

each street crossing would not vary enough to affect the estimate of quantities or the projected location, the latter being controlled largely by the street crossings. The writer has actually covered an area 5,000 ft. long by 1,000 ft. wide by this method between 8 A. M. and 4 P. M., and the contours have been transferred by means of black lead transfer paper and inked in on the map by 6 P. M. the same day, and profiles of lines actually run have proved the accuracy of the work within the limits of the scale. Figure 52 shows a portion of the territory covered, and is a fair sample of the kind of country.

When sufficient information had been obtained, necessitating several preliminary lines and full topography on each, a tenta-

tive final location was made. Of course, before this line was decided on, even tentatively, several projections had been made and estimates of cost on all of them; where there were so many different combinations possible, by changing the line or grade of the proposed railroad, or the line or grade of the street, the only way any proper decision could be arrived at was by estimating the cost of each different line as closely as possible. An idea of what such an estimate may involve is shown in Table 2 (page 152), which shows the actual comparison between two lines as actually projected, but not including the right of way:

In comparing two or more lines, it is extremely important that

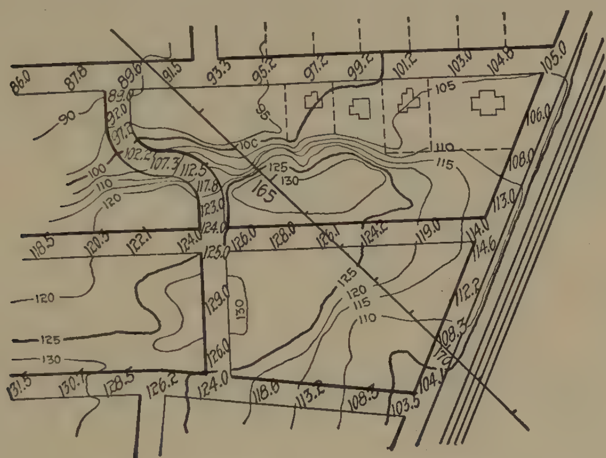


FIG. 52.—SHOWING CONTOURS FILLED IN.

the estimates of quantities and cost of both lines should be made by the same man, as estimates always involve more or less the personal equation. Two or more men may make the comparison if a check is desired, but not separate men for each line.

In projecting the location the width of roadbed as well as width of street, must always be taken into consideration in calculating clearances over or under streets; for instance, in Fig. 53 a four-track road on a grade of 1% and an 80-ft. street with a grade of 3%, crossing over the railroad and at an angle of 60%.

Let A B C D be the center line of the R. R. with a 1% grade rising from A to D, and E B F the center line of the street falling from E to F, it will readily be seen that the clearances must

TABLE 2.

	Price	Unit	"A" LINE Quantity	"A" LINE ost	"B" LINE Quantity	"B" LINE Cost
Rock Excavation	$1.40	cub. yd.	469 010	$656 614 00	436 8,6	$611,570 40
Earth "	.30	"	234,271	70,281.30	[illegible]7 031	20,109.30
Overhaul	.03	"	107 4 3	3,222.69	173 246	5 197 38
Ashlar and Arch Masonry	9 50	"	44,692	424 574.00	46,953	446,[illegible]53.50
Rubble Masonry or Concrete	7.00	"	7 623	53,3[illegible]1 00	12,968	90, 76 00
Subway Construction	110.00	lin. ft.	594	65,340 00	1,010	111,100.00
Viaduct (Reinforced Concrete)	140.00	"	1,690	236 600.00		
Steel in Bridges	.035	lb.	3,573,530	125,073.55	4,116,180	144,066.30
Macadam	1.25	sq. yd.	26,300	32,875.00	20,500	25,625.00
Brick or Asphalt Paving	2.25	"	11,400	25,650.00	3,000	6,750.00
Track La'd and Ballasted	2.20	lin. ft.	80,322	176,708 40	72,480	159,456.00
Crossovers	450.00	each	7	3,150 00	7	3,150.00
Fencing	.10	lin. ft.	53,486	5,348.60	48,324	4,832.40
Supporting streets during construction; changing sewers, water pipe, etc.	......	......	......	60,000.00	......	67 000.00
Stations	......	......	4	25,000.00	4	25,000.00
Draw Bridge	......	......	......	70,000.00	......	....
TOTAL				$2,033 798.54		$1,720,686.28
Add 10% for contingencies, engineering, etc.				203,379.86		172,068 62
TOTAL				$2,237.178.40		$1,892,754.90
Length			26,715 ft. = 5 06 mile		24,160 ft. = 4.58 mile	
Average Cost per Mile			$442,130.		$413,265	
Total Curvature			235°-15′		79°-24′	
Maximum Curve			3°		4°	
Total Rise going North			54.75 ft.		72.55 ft.	
" " " South			77 15 "		81.25 "	
Ruling Grade			0 85% on 3° curve		1 2%	

be calculated between the grades at the points F and C and not between the grades at the point of intersection of the center lines. In all cases, even on preliminary projections, this should be taken into consideration, as its effect may be a matter of considerable importance where the available height for clearance is limited. The writer would hardly think it necessary to call attention to this fact, which is almost self-evident, except for the fact that he has known of serious inconvenience at least, having been caused by neglect of this in assuming the clearance at the intersection of the center lines.

In the case noted, the distance from B to C is almost 60 ft., making 0.6 ft. difference in elevation, and from B to F about 50 ft., which on a 3% grade makes a difference of 1.5 ft., so that

FIG. 53.

in order that full clearance may be obtained at the point G the clearance at B must be at least 2.1 ft. greater than the minimum required.

In projecting the location through valuable property an endeavor should always be made to avoid cutting it up in such a way that the portion remaining will be of little value to the owner; in such cases the railroad will finally have to pay for all the damage, often as much as the whole property is worth. Underestimates of cost are often due to this cause, among others.

As soon as the final location had been tentatively decided on, the detailed accurate survey of the towns was taken up. Usually the line ran in a more or less general way through a tier of blocks, though none of the towns was laid out rectangularly; the first preliminary line having been run through a street bounding one side of the tier, a second line was run through the street on the other side, and the two lines connected through the side streets, forming a series of closed traverses.

These lines were all carefully marked by spikes of various kinds, railroad spikes, 6-inch nails, both cut and wire, and larger cut spikes, driven into the pavement, and marks made on them with a cold chisel for both line and distance. These spikes were not only put in at angle or instrument points, but also, at least one every hundred feet or a little less; generally at uneven distances, as they had to be driven through joints in the paving. Both lines were stationed so that any point could be referred to by its station number, and any point used afterwards as an instrument point, for any purpose of further surveys, for locating the streets, buildings, property lines, etc.

The method of stationing can be readily understood by the diagram (Fig. 54). The line A B C D is the main preliminary, E F G H being a line nearly parallel, and B F, C G, D H, etc., connecting lines through side streets; on the line E F G H stationing was started at zero at A and run continuously along this line, the cross lines being stationed, with zeros at B, C, D, etc., and running towards F, G and H respectively, and recorded by sketches as shown (Fig. 56), which shows the notes of the cross line between F and B.

It should be noted that the original map from which Fig. 54 has been reproduced was on a scale of 200 ft. to the inch, twice as large as the reproduction, and colored inks were used (as noted), making the information conveyed by the map much clearer than is possible in black and white only.

In measuring any of these lines, although the spikes, etc., might be driven at odd stations, the measurements were always broken at the even stations, these points being marked temporarily if they could not be marked permanently; thus, starting at B, Fig. 54, the measurement was first taken to, and a point marked at, Sta. 97; it was then found that the next place at which a spike could be driven on line was about 7½ feet further. This spike was then driven, and a chisel mark made on it for line, and another chisel mark at right angles to the first, near the middle of the head; the distance was then measured from Sta. 97 to the cross cut, and found to be 7.68, the station of the spike being thus recorded (see Fig. 55); the next station, 98, was then measured in directly by a 100-foot measurement from Sta. 97, and a mark made. This avoided chances of error from additions or subtractions for plus

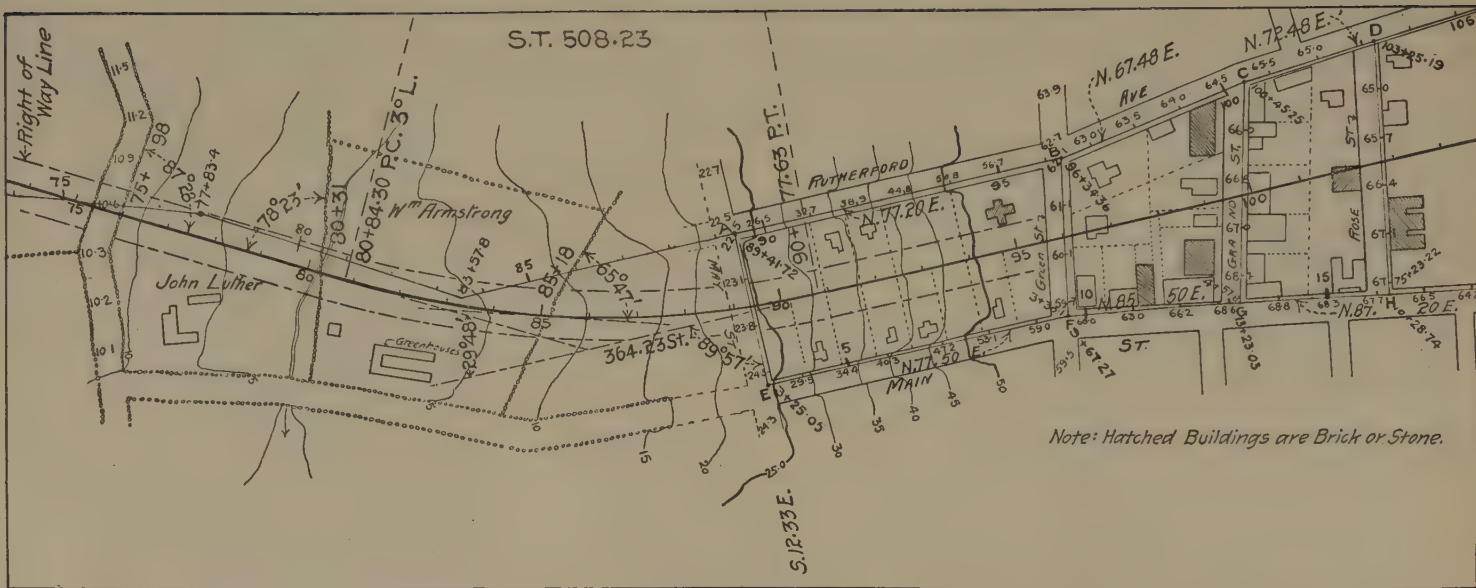


FIG. [illegible].—LOCATION MAP NEAR TOWN, SHOWING METHOD OF RUNNING PRELIMINARY LINES, ETC.

Original map 200 ft. to the inch, Preliminary Lines in red, Elevations of Ground in blue, Final Location heavy black. All courses are referred to true meridian, and are "calculated courses." Contours in burnt sienna, Plusses of Property Line intersections with Final Location, in black along Property Line.

distances. As a check, when an angle point was reached, the measurement was repeated by going back over the line, taking the distances between each spike, and adding all these together, the two measurements being required to check within the required limit of error.

The form of notes for the first line A B C D was substantially that used on ordinary preliminary work, with the added detail necessary, showing ties to points so that they might readily be found, etc. A sample page is shown (Fig. 55). The notes for the line E F G H are similar, except for the sketches showing the connecting lines B F, C G, etc. (See Fig. 56.)

As soon as these traverse lines were satisfactorily completed, surveys were commenced to locate carefully all buildings, land lines, etc., through a strip about 200 ft. wide, through which the tentative location passed, as shown by the 200-ft. to the inch map. A map on a scale of 50 feet to the inch was made to show the results of these surveys, and on it such minor adjustments of the projected location were made as were considered necessary.

An arbitrary system of co-ordinates was established for each town, and the stations of all points on the traverses calculated from the assumed bases. As soon as the location was established, the length of the line and the co-ordinate stations of P. I.'s, etc., were calculated, the limits of accuracy within which the surveys were kept obviating the necessity of actually running the line in on the ground before the right-of-way was obtained and the buildings removed.

This being accomplished, the final location of the whole line was run in on the ground, except that portion through the towns, that is, the built up portion, the line being run up to the edge of each, and connected with the co-ordinate system, and then the station of some point on the other side, on the located line, calculated, and the survey continued, thus making the stationing continuous, and obtaining a continuous profile. Where possible, as in the case noted (Fig. 54), where connections were made with the co-ordinate system at both May and Green Streets, connection was made with two points on the co-ordinate system, thus affording a better check than where possible to connect with only one point.

In the case shown, Fig. 54, the tangent beyond Sta. 91 was

established on the ground by calculating exactly its intersection with the preliminary lines A E and B F, and establishing these points on the ground; the line thus obtained was then run back to an intersection and the curve run in, the line continued to Green Street and then stopped; the alignment and length were then calculated through the town, and the continuous stationing established on the other side of it.

As soon as the location was staked out surveys were made to determine accurately the plus of each property line at its intersection with the centre line, which included, of course, the both sides of all streets and roads crossed, the angle each made with the centre line and the correct location of all these lines for at least 100 ft. on either side. Where curves crossed property or street lines the intersection angle of these lines with the tangent to the curve at the point of intersection was taken. This information when obtained was inked in directly on the 200 ft. map, the projected location having been left in pencil until the line had been run in on the ground, at which time careful ties were taken to the preliminary lines, and then the location, as finally run in, inked in on the map.

Surveys were made of all streets for at least 200 ft. on either side of the centre line, or as much farther as expected changes of grade might make necessary, all buildings were located and their character noted (3-story brick dwelling, 2-story frame, etc., etc.); property and curb lines, all sewer, gas and water pipes, electrical conduits, etc., with their manholes and elevations, were also located. In many cases large trees were tied in, and in all cases all telegraph, telephone or other poles, and the height, number and kind of wires on each, and name of owning company, and especially so where these latter were likely to interfere with construction.

As a basis for these surveys of street crossings, where possible, the correct center line of the street was established from information obtained from the local authorities or from private surveyors, this line intersected with the center line of the railroad, and a heavy iron pin driven at the point of intersection and marked by chisel cuts, the line of the street, as established, being also carefully referenced at each end, and far enough away so that there would be no chance of the points being disturbed when construction was started.

Sta.	Dist.	Ang.	Mag. Course	Cal. Course	
100					
⊙ +3·21					
99					
⊙98					
⊙ +7·68					
97			N 70·30 E	N 67·47·40 E	
△ +34·36		9·32·40 L		Trolley Line	
96 ⊙					
95 ⊙					
94 ⊙					
93 ⊙					
⊙ +48·2					
92 ⊙					
91 ⊙					
90 ⊙					
			N 77·30 E	N 77·20·20 E	
△89+41·72		0·30·20			
	583·92		N 76·30 E	N 76·50 E	
△83+57·8					

In measurement 96+34·38
89+41·72
6 92·66

Check back 692·61 — Calc distance 692·64

9·33·00
19·05·00
28·38·00
38·11·00

0·30·30 X
1·00·30
1·31

FIG. 55.

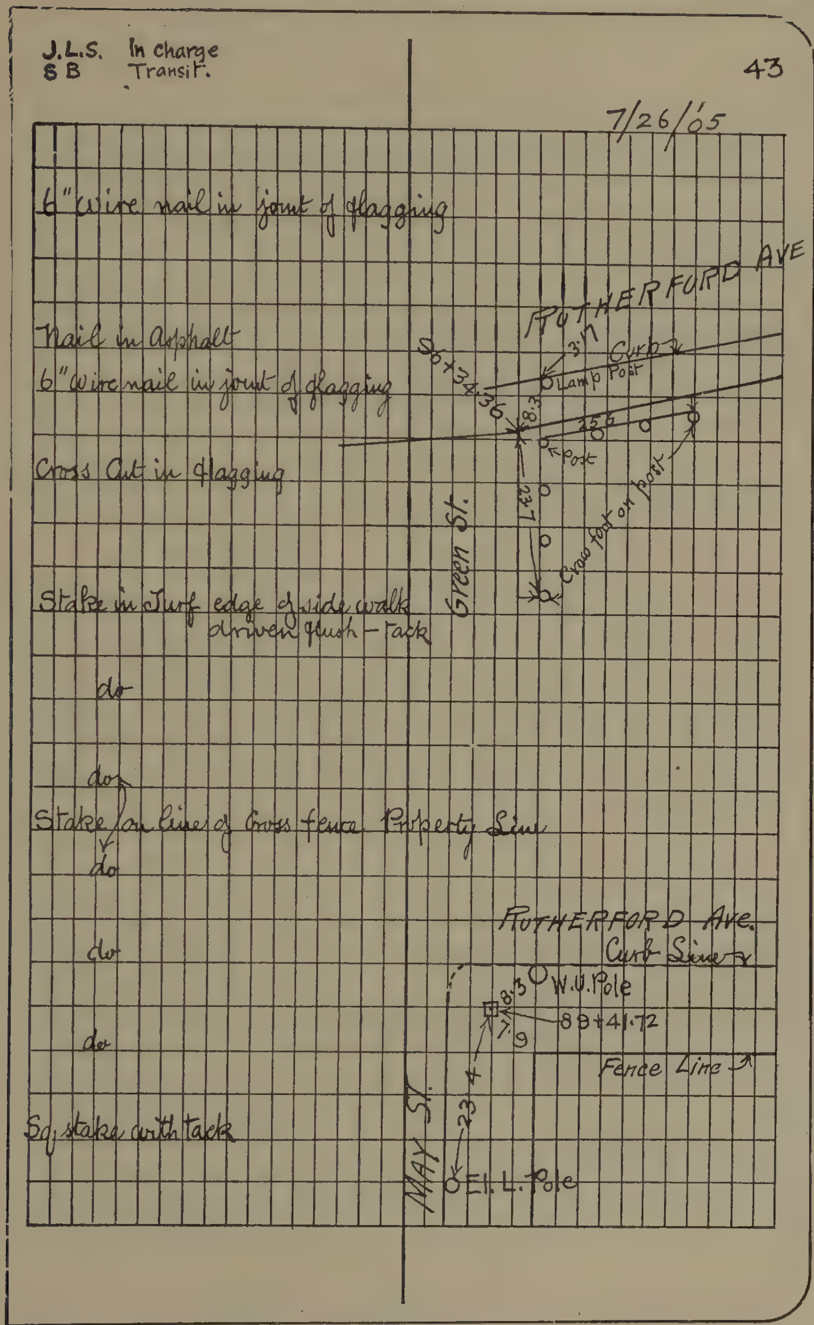

J.L.S. In charge
S B Transit.
43
7/26/05
6" wire nail in joint of flagging
Nail in Asphalt
6" Wire nail in joint of flagging
Cross Cut in flagging
Stake in Turf edge of side walk driven flush – tack
do
do
Stake on line of Cross fence Property Line
do
do
do
Sq. stake with tack
ROTHERFORD AVE
Curb
Lamp Post
56+34.36
3.7
8.3
25.6
Post
23.7
Crow foot on post
Green St.
ROTHERFORD Ave.
Curb Line
W.U. Pole
8.3
89+41.72
7.9
Fence Line
23.4
MAY ST.
El. L. Pole

FIG. 55.

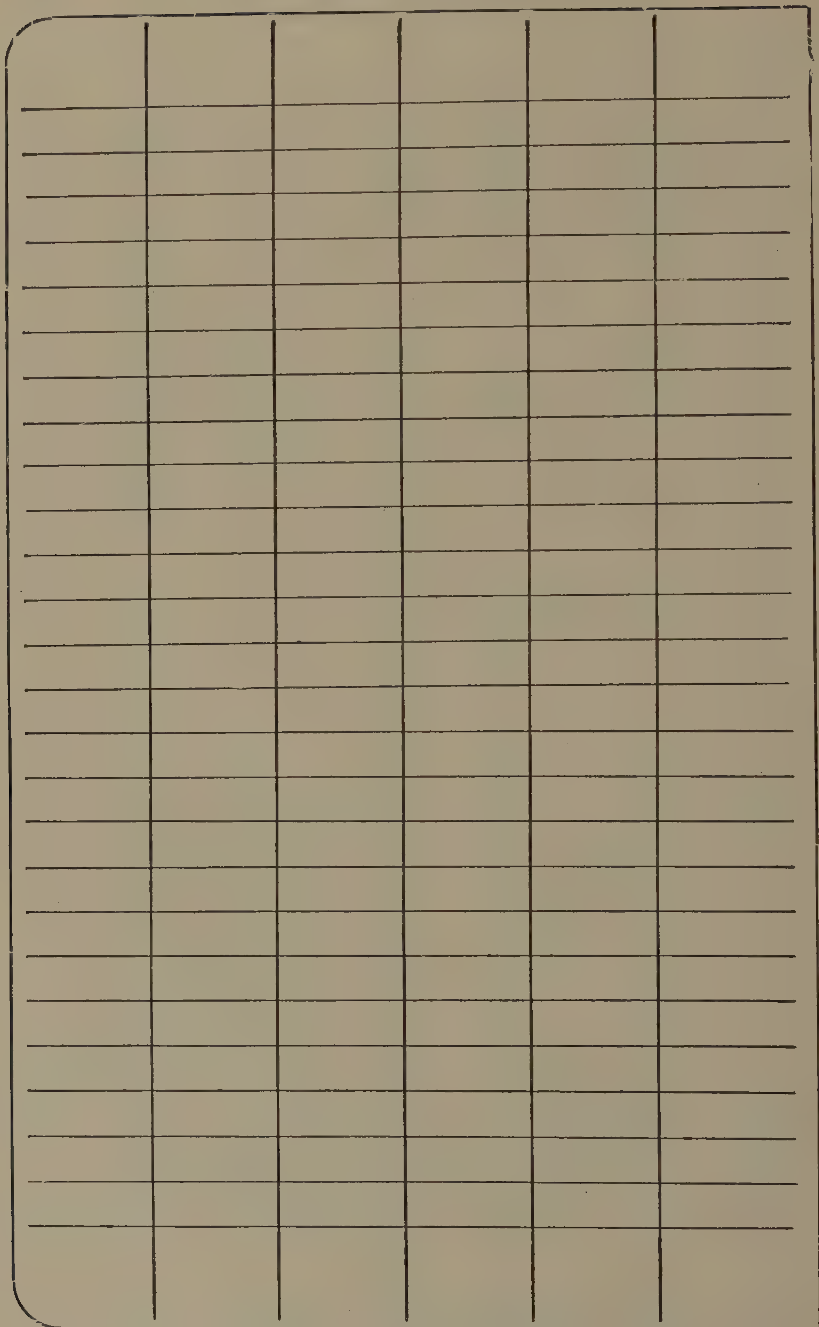


FIG. 56.

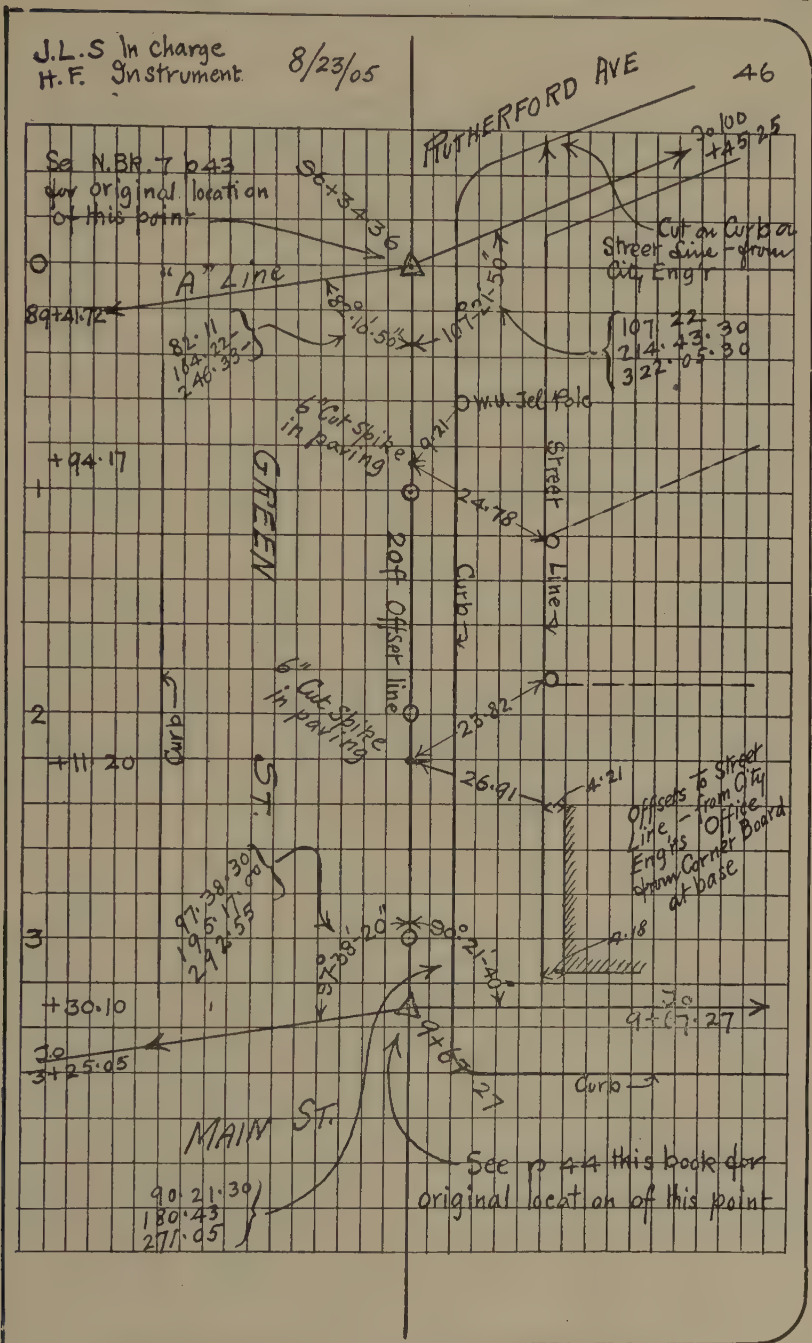

J.L.S In charge
H.F. Instrument
8/23/05
46
RUTHERFORD AVE
See N.BK. 7 p 43 for original location of this point
"A" Line
89+41.72
+94.17
GREEN
ST.
Curb
2
+11 20
Street
Line
W.U. Tel Pole
20 ft Offset line
Curb
6" Cut Spike in paving
24.78
25.82
26.91
Cut on Curb at Street Line from City Eng'r
Offsets to Street Line — from City Eng'rs Office from Corner Board at base
3
+30.10
3+25.05
MAIN ST.
Curb
See p 44 this book for original location of this point

FIG. 56.

The plans of the crossings were platted on a uniform scale of 20 ft. to the inch, and generally on uniform size sheets, 24″ × 36″, except where longer sheets were necessary, the width being kept always the same, and a standard title placed in the same relative position in the lower right-hand corner of the sheet Fig. 57, these plans thus serving not only as a basis for working out any desired changes, either in grade or location of the street, but also as site plans for working up the bridge and masonry plans. Cross sections of the street and railroad were taken at least every 50 ft., and the elevations thus obtained platted on this plan (decimal points showing location), making it complete in every way. In the reproduction of the plan in Fig. 57 the title was inadvertently placed in the body of the drawing instead of in the lower right-hand corner, as was the rule on this survey; the advantage of having all the titles in one place for convenience of filing, is obvious.

Through the towns, where the located line was not actually run in, the points and stations where the location crossed each street were fixed on the ground by calculation from the established traverse, and levels taken there, the ground between the streets being either assumed to be on a uniform slope, or such irregularities as could be determined, obtained by the hand level, thus making the profile continuous; the important points, as far as fixing the grade line being thus determined accurately, and the ground between, near enough for purposes of estimating quantities. Site plans of these crossings through the towns were not prepared until after the line had been actually run in.

As soon as the tentative location had been decided, and during the time the surveys of the towns were being carried on and the final location staked out, work was started to obtain copies of all maps filed at the registries of deeds affecting property within 200 ft. of the centre line, maps at the various town clerks' offices of street layouts, etc., and sufficient information obtained either from the town engineers or other authorities, or from local surveyors, who were paid for their time and trouble, so that all property and street lines could be accurately established on the ground. One man was kept busy for nearly two months on this work on a stretch of line about 12 miles long, and the locating engineer devoted a large portion of his time to these matters during the same period.

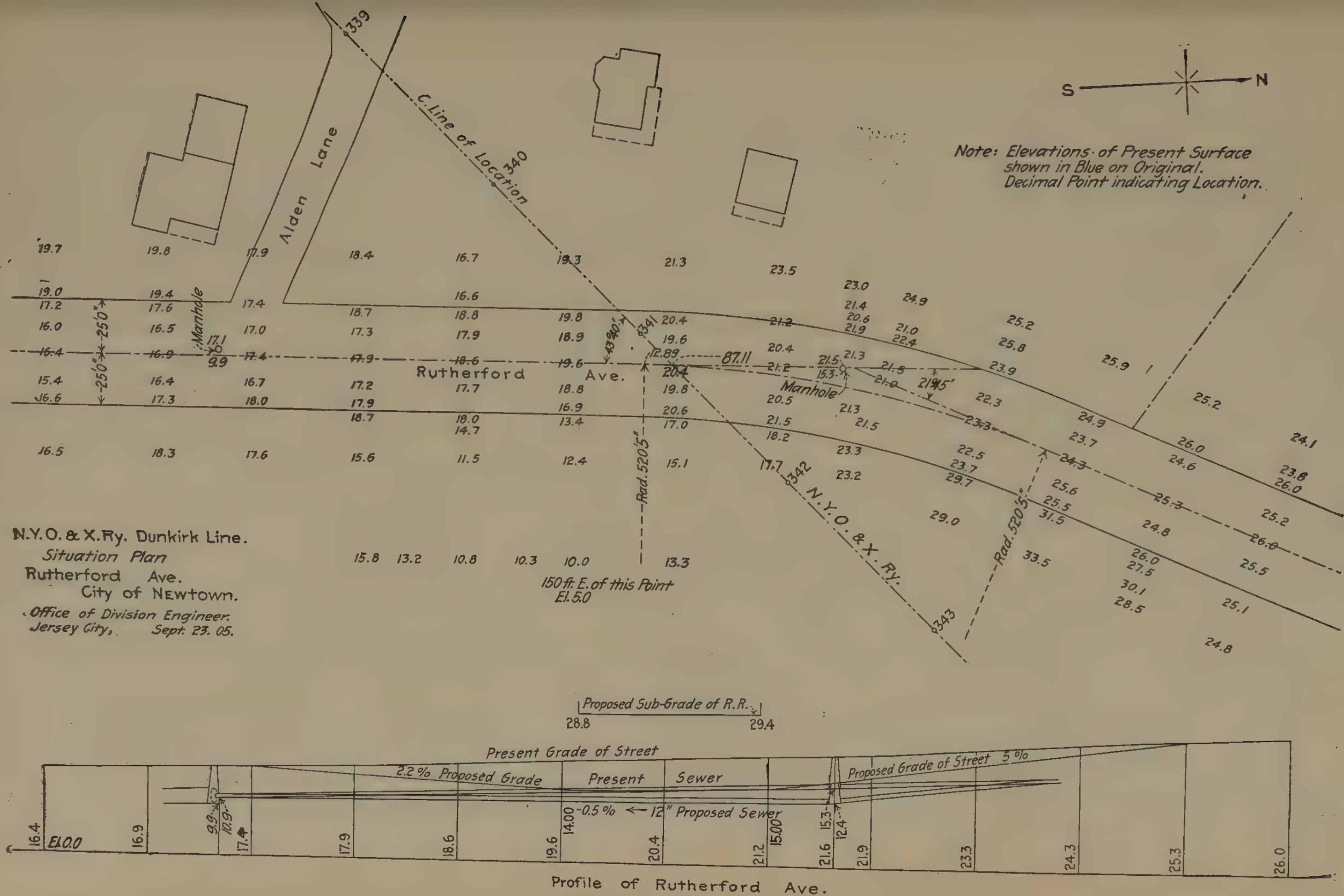

Note: Elevations of Present Surface shown in Blue on Original. Decimal Point indicating Location.
S
N
Alden Lane
C. Line of Location
339
340
341
342
343
Rutherford Ave.
Manhole
Rad. 520.5'
N.Y.O. & X. Ry.
150 ft. E. of this Point El. 5.0
N.Y.O. & X. Ry. Dunkirk Line.
Situation Plan
Rutherford Ave.
City of Newtown.
Office of Division Engineer.
Jersey City, Sept. 23. 05.
Proposed Sub-Grade of R.R.
Present Grade of Street
2.2% Proposed Grade
Present Sewer
-0.5% ← 12" Proposed Sewer
Proposed Grade of Street 5%
El. 0.0
Profile of Rutherford Ave.

Fig. 57

In projects of this kind, it is even more important than on a steam railroad that a determination as to the character and equipment of the road should be arrived at at the earliest possible moment. Steam railroad standards are now fairly well settled, but in this particular case the question arose whether clearances should be provided for standard railroad equipment or whether only for such cars as were then and are now in use on the New York Subway and elevated railroads, and which would be the type of cars principally if not wholly used for the principal business of the road. This matter did not rest entirely with the engineering department, and a final decision to provide for clearances for standard equipment (Pullman cars) was not arrived at until late. As it was entirely improbable that freight trains would be run over the road, it was not necessary to provide the extra height at overhead crossings for a man standing on a freight car. The final minimum clearance adopted for overhead structures was 20 ft. between sub grade and grade of street, made up as follows: Sub grade to top of rail, 2 ft.; top of rail to under side of structure, 16.0 ft.; bridge floor, 2 ft. For streets underneath the railroad, 16 feet—14 ft. clearance over street, 2 ft. for bridge floor. Where possible, of course, where the street was underneath, clearance was obtained so that deck girders could be provided for, advantage being taken of the possibilities of getting columns on the curb lines, and thus reducing the length of clear span.

The necessity of making tentative layouts for the stations, which in turn necessitates a tentative scheme of operation, in order that their effect on the quantities of excavation and embankment may be calculated, at least approximately, has been alluded to previously, and other instances will constantly occur, showing the many problems which will come up from time to time to affect the location of such lines as these, which are not generally considered on ordinary location; but in any event the principle holds good that the engineer must always keep in mind and have a very clear idea of the necessities of operation as affecting the location.

The party used on this work consisted of nine men besides the locating engineer. When line was being run where there was much chopping to do, all the men were used on the transit party; in getting the topography, etc., they were broken up into parties of two or three men, one man being kept in the office as draughtsman.

The organization and salaries paid under the locating engineer were as follows:

Assistant engineer	$100 to $125
Transit man	90 to 100
Leveller	80 to 90
Level rodman	65
Head chainman	60
Rear chainman	50
Back flag	30
Two axemen	30

The average rate of progress with this party from the starting of the preliminary to the completion of the final location, site plans of street crossings, accurate surveys of towns, etc., as previously indicated, was about two miles per month.

Right of way maps at a scale of 100 ft. to the inch were contemplated on this work, to be platted on separate sheets of uniform size, probably 18″ × 30″, with wide margins on left hand end for binding.

These right of way maps, besides showing all necessary measurements, monuments, stakes, etc., for defining the property acquired for right of way, should show the name of the original owner, where his deed is recorded, the place, book and folio where the deed to the railroad is recorded, and date of transfer; any restrictions, reservations, or easements should also be noted on the map.

Deed maps can be made on tracing cloth same size as deed and blue prints filed with deed, or deeds may be obtained, printed on Crane's bond paper, the last page being blank, and the map drawn directly on this, of which a blueprint may be made for filing with the records of the engineering department, the original map then being always sure to accompany the deed.

CHAPTER VIII.

ESTIMATES, AND TABLES OF QUANTITIES.

Making an estimate of the cost of engineering work of any kind is in many ways one of the most important things which an engineer is called upon to perform, and one which calls for the exercise of a large amount of judgment, based on actual experience; and in view of the fact that it is in this connection that he gets closest in touch with outside interests, whose ideas of the whole engineering profession are often based on just that part with which they come in contact, and especially with the financial interests without whose aid no engineering work could be carried on, it behooves every engineer to use particular care in this work to the end that, on the one hand, the estimate shall not be so much above the actual cost of the work that capital will not be attracted to the proposition, and, on the other, so low that the enterprise will be in danger of ruin before it is completed, on account of financial embarrassment, and the capitalists who have invested their money suffer financial loss and so discredit any future engineering reports.

To the locating engineer this matter is of especial importance, not only in making an estimate of the cost of a line in order that the financial interests may determine whether it will probably prove a profitable venture or not, but in cases where two or more lines or routes are in question, serious errors may be made by adopting the wrong line unless proper care be taken in estimating the cost of construction of the two lines so that they may be properly compared.

Estimating is, to a certain extent, of course, a matter of guess work and judgment, but every effort should be made to collect all available data in connection with the work by working out the plans in as much detail as possible, so that the uncertain elements may be eliminated to the greatest possible extent. As noted elsewhere, in making comparative estimates, especially of two or more

railway lines, the estimates of both lines should always be made by the same man, in order to eliminate the personal equation as affecting one line differently than the other, although as a check two or more men can estimate both lines if desired.

Estimates of the cost of building a railroad and getting ready for operation may be divided into the following items:

1. Right of way.
2. Grading (building the roadbed to sub-grade).
3. Structures (bridges, culverts, etc.).
4. Track and ballast (furnished and laid.)
5. Stations, yards, etc.
6. Equipment (rolling stock, machine shops, water tanks, signals, etc.)
7. Terminals.

In comparing two or more lines, the locating engineer is only usually concerned with the second and third items, the quantities affecting which, are usually worked up from the profile either of the projected or final location, as the case may be. Items 1 and 4 will affect the line where the length of one line is greater than the other, or where, as is sometimes the case, the right of way on one line may be more expensive. Where the cost of maintenance on one line is liable to be much more than on another, this must, of course, be given due consideration, as well as other factors of line and grade which influence operating expenses.

In making an estimate of the quantities involved before the final location is run in on the ground, it is very necessary that a profile be obtained on which to base the estimate, which will closely approximate that of the final line. This is accomplished by the method previously described by getting the profile of the projected location from the topographical map, which profile should be worked up in as much detail as possible and show nearly if not quite as much information as the profile of the final location. (See Fig. 27.)

On this latter, if proper soundings have been taken in the cuts and at all foundations, a very close estimate can be made of the amount of rock in the cuts and necessary depths to which foundations of bridges or other structures, either of piles or masonry, will have to be carried. On the estimate from the projected location, however, all these things will have to be dependent on the judgment of the engineer, and it is necessary therefore that during the reconnaissance, and on every possible occasion, he take full

notes of the probable character of the ground, so that his judgment will be based on actual observation, as far as possible.

As soon as the profile of the projected location has been made and the grade line fixed, the writer generally indicates on it at each cut what he judges to be the per cent. of rock, what slopes shall be used in calculating the quantities, where allowance must

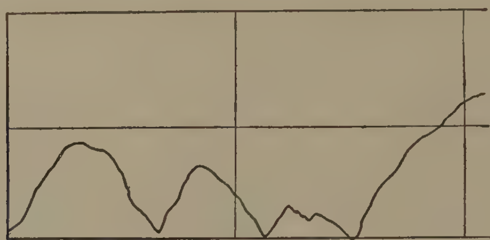


FIG. 58.

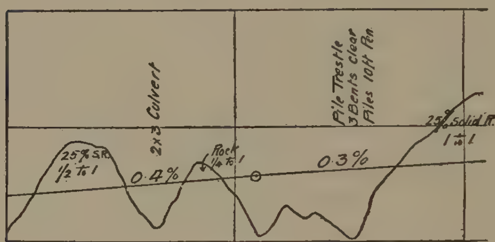


FIG. 59.

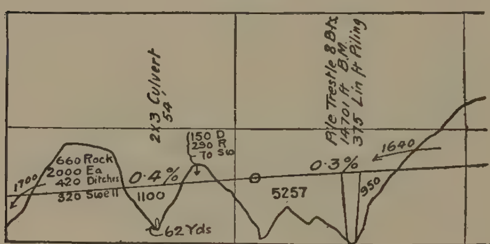


FIG. 60.

be made for steep transverse slopes, and then at each opening what the character of the structure is to be; and then turns the profile over to the draughtsman to calculate the quantities. Figs. 58, 59 and 60 indicate the different stages of work on the profile. Figure 58 shows the profile as taken from the map of the projected location. Figure 59 shows the grade line fixed and the addition of the notes of the locating engineer, and Fig. 60 the same profile

after the quantities have been calculated by the draughtsman and distribution of material made. On extensions to existing railroads standard plans of structures are usually furnished to locating engineers, and these are used in making estimates; these plans should show tables of quantities for the different heights or lengths of structures within the limits where they may be used. On short lines, where it would not be advisable to prepare a uniform set of plans covering all possible structures, the locating engineer is often left to his own resources, and in such cases usually with no reference books available. Tables of quantities in such standard structures as are commonly in use on railroad construction are appended, and may be used as representing fair quantities for the best modern practice. (Page 181 et seq.)

It is too often the case that estimates are made by locating engineers entirely on their own ideas, and simply a lump sum total or average cost per mile turned in; where time and money permit, and not a little of either is needed, the estimates should be made out in detail, much the same as a regular monthly or final estimate on construction, as shown in Fig. 61, which shows an example of an estimate in detail of each cut and fill and each structure, and in Fig. 62 a summary of a 10-mile section. The latter will usually suffice to send to headquarters, the former to be kept in camp and filed with the other records of the survey.

In many cases contract prices change materially between the time the original estimate was made and the time of construction, in which case, unless the estimate has been recorded in good shape and in detail, the work has to be done all over again; small revisions may be made from time to time, which may necessitate changes; in any event, the chief engineer, or whatever official is directly superior to the locating engineer, should be able to check closely the judgment of the latter, not only in making the estimate, but in planning the necessary structures, and in order that this may be done, details should be submitted with the estimate, and to this end the profile should show fully not only the grade line and the quantities in cuts and fills, but how the material is to be disposed, what proportion will probably be rock (no attempt should be made to make other classification than earth and rock, except in some special cases), and what the character of the various structures is to be.

The various structures ordinarily used on new construction are generally designated on the profile as follows:

Culverts, by their clear opening inside, the larger dimension being usually the height, as—

2×4 Box culvert.
3×6 Arch culvert (the 6 ft. being height at centre).
3×5 Double box, etc.

Arches, by their span, as 15-ft. arch, etc., when standard plans are followed. In special cases the height of side walls from floor to springing line and rise of arch may be noted.

Steel Bridges, by their clear span between abutments (Note.—Clear span of steel will be a little more than this, but that is a matter for the steel designer) and kind of bridge, as—

90′ Deck girder.
80′ Through girder.
150′ Truss, etc.

Wooden Bridging, pile or framed trestles, either by their length or the number of bents, as—

72-ft. pile trestle (or frame trestle, as the case may be), or
7 bents, pile trestle (if the bents are spaced 12 ft. on centres).
The length in this case being the total length of the bridge (centre to centre of end bents), and not the clear opening.

Log Drains, or timber culverts, are built often, where timber is plentiful, of sizes to permit inserting cast-iron pipe at some future time. The size of pipe required is determined and the size of log drain given to correspond. Thus, for a 36″ cast-iron pipe a $4' \times 4'$ log drain (inside dimensions—clear) would be used and so designated.

Pipes.—All pipes are designated by their inside dimensions, as—

24″ Vitrified pipe.
36″ Cast-iron pipe.

and, when necessary, concrete or other foundation noted.

It should be self-evident that with equal judgment and experience a much more reliable estimate can be obtained from a profile on which the details are worked out as carefully as possible, than when, as is often the case, and when, as is generally the case when the so-called field location is made, an estimate is made from the profile of the preliminary line. In the latter case the preliminary line is run, presumably, somewhere near the final location and a profile is obtained of it. Then, from what he recollects of the country, the locator modifies this profile by drawing dotted lines showing what he thinks the final location should make it. If he has a good memory he may get somewhere near it, but in no event can he possibly hope to get as close an approximation as can be obtained from a profile of a projected line taken from a topographical map. Besides inaccuracies of elevation there will be differences of distance and curvature which may and undoubtedly will considerably affect the grade line, sizes of structures, etc.

The fact that one so frequently hears engineers' estimates spoken of so disparagingly indicates the necessity of great care in this regard; and the writer believes that one of the most important measures to be taken to insure the necessary accuracy is to secure all the information possible by soundings, borings, etc., in all cases of excavation; and yet it is frequently extremely difficult to get permission or money to make these. The practice of the C. O. & G. R. R. of having soundings made in all cuts, and at all bridge sites, by the locating party is one which is to be heartily commended, but which is not followed nearly as frequently as it should be. In the case of any important structure, borings should be made by a well driller or diamond drill, if the character of the foundation cannot be otherwise ascertained.

Of course there is plenty of room for the engineer to exercise his judgment even after having obtained the most minute information, and as long as estimates have to be made, there will always be times when some kind of an estimate has to be made on the most meagre information. In the case of a railroad, the first estimates are made by the man who rides over the country and has to make a guess, from just what he can see, of what the line will cost per mile. The estimate from the projected location has more information to go on, and the estimate from the final location should have all the information available. At least 15% should be added to the preliminary estimate to cover engineering and contingencies, and all quantities estimated liberally. On the final location, pains should be taken to have the quantities more nearly correct, and 10% is usually added. Usually the estimate from the final location should show considerable saving over the preliminary estimate.

The writer has known men who could look over a profile with just the bare grade line on it and guess the yardage within 10% easily, or even ride over a line in open, undeveloped country, and approximate the cost within the same limits before a stake had been driven, but these methods are not safe for the engineer, and especially the young man. It is often said by experienced men that they can guess, closer than many can estimate from details, and this has had a certain amount of truth in the past, but with the increasing population and the fact that the location of new

TABLE III.

Removal of old buildings	Lump sum	
Excavation—Old masonry	Cu. yd	$0.80
" Solid rock	"	2.50
" Unclassified	"	1.00
Piling in permanent work below cut-off	Lin. ft	.75
Timber in permanent work	M. ft. B. M.	32.00
Concrete, various classes	Cu. yd	5.00 to 15.00
Stone masonry, 1st class	"	41.00
" 2d "	"	10.00
" 3d "	"	6.00
Brick masonry	"	12.00
Vitrified sewer pipe, 8″ (furnished and laid)	Lin. ft	.38
" 12″ "	"	1.00
" 18″ "	"	2.55
" 24″ "	"	2.65
Brick masonry in sewer manholes	Cu. yd	14.00
" sewers	"	15.00
Straight C. I. water pipe, delivered, but not laid	Net ton	29.00
Special " "	"	55.00
Straight C. I. gas " "	"	30.00
Special " " "	"	55.00
Laying C. I. pipe, 4″	Lin. ft	.25
" 8″	"	.40
" 12″	"	.60
" 16″	"	.80
" 20″	"	1.25
" 24″	"	1.45
" 30″	"	1.60
4″ wrought iron pipe, with fittings	"	.70
3½″ " "	"	.48
3″ cocks and boxes for water pipes	Each	10.00
6″ "	"	22.00
12″ "	"	75.00
20″ "	"	320.00
Double-nozzle fire hydrants and appurtenances	"	85.00
6″ blow-offs	"	35.00
4″ cocks and boxes for gas pipes	"	10.00
8″ "	"	23.00
12″ "	"	40.00
16″ "	"	75.00
2½″ electric ducts	Lin. ft	.50
Four-way electric ducts	"	.35
Wrought iron	Lb	.035
Cast iron	"	.04
Steel bars for concrete reinforcement	"	.035
Expanded metal, No. 10 gauge, 3″ mesh	Sq. ft	.045
Erection of structural steel	Net ton	16.00
Removal of old bridges and loading on cars	Lump sum	12,000.00
Waterproofing, various classes	Sq. ft	.20 to .60
Pavements—Granite block relaid	Sq. yd	.30
" Asphalt	"	4.00
Flagging—New, in place	Sq. ft	.27
" Retrimmed and relaid	"	.10
Curbing—New, in place	Lin. ft	1.00
" Retrimmed and relaid	"	.50

railroads is becoming more and more complicated by the necessity of avoiding grade crossings of other railroads and often of highways, it will be safer for the engineer to get the details as closely as possible, and subdivided into as many separate items as he can, and calculate his quantities and figure his estimate from the best and most data he can obtain.

Although it is a matter somewhat removed from ordinary railroad location, the schedule Table III. shows the various items involved and the prices used in estimating the cost of eliminating the grade crossings of a four-track trunk line through one of the Eastern cities. Of course, the location of a new railroad rarely if ever involves as many complications, but it is never beyond the realms of probability that a new line might have to enter a city as large as this and might involve similar complications, and railroad estimates may range from those required for the simplest line to such as this. The estimate was made about 1904, and prices are applicable to that time.

Where the judgment of the engineer comes most into play, once the quantities have been determined with more or less accuracy, as the necessities of the case may seem to require, is in determining the probable cost of the various units, and every engineer should have on hand cost data accumulated from his own previous experience, and from whatever other source he can get them. The writer has used a loose leaf note book to considerable advantage in tabulating his own data. The records are arranged, first under the General Headings such as Railroads, Sewers, Water Supply, Streets and Highways, etc. These in turn are subdivided, as for instance, under Railroads, into:

Clearing and grubbing.
Excavation—Unclassified.
" Earth.
" Hardpan.
" Loose rock.
" Solid rock.
In water.
Etc., etc.

Three leaves of the note book are devoted to each subheading; on the first leaf of the three is recorded prices of work with which he has been connected; on the second, prices of work which he has seen or knows something of, but not actually connected with, and, on the third, contract prices from the technical journals

where only the general conditions are surmised, but excluding any where there was absolutely nothing known of the conditions.

In estimating the costs of work, on the construction of a new railroad especially, though in fact anywhere, very careful consideration should be given to the facilities of transport and the cost of getting the materials to the site of the work. If a tunnel is involved, consideration must be given to the fact, if it is a long one, that quite a large amount of machinery, boilers, drills, air compressors, etc., will have to be hauled to the site from the nearest railroad. Similarly, for all structures which cannot be built of materials already at hand in the country, proper allowance must be made for the cost of haulage, often long distances over poor roads. This is an item which is too often lost sight of, although its influence on the cost of the work is considerable.

The method of making up an estimate of the costs of a railroad followed generally by the writer is based on that used on the C. O. & G. R. R., and is, as previously noted, in much the same form as that used on a regular estimate on construction; and where such blanks are to be obtained, the estimates should always be made out on them.

On that road each mile was totaled separately, and only the totals sent to heaquarters, the details being filed in camp and turned in with all the maps, note books, etc., relating to that particular survey when it was completed; the preliminary sheets were left in pencil and the estimates of the final location inked in (see Figs. 61 and 62). The writer would especially call attention to the method of distributing the quantities of excavation and the method of balancing the quantities. The total excavation for any particular section, say for one mile, plus the borrow, should equal the embankment plus the waste minus the swell. Where the totals were made up for each mile, any materials hauled from one mile or section to another were noted and taken care of in balancing the quantities, and similarly for any length of section.

There is always a liability, especially in preliminary estimates, to forget small details, as, for instance, the masonry quantities in culverts will be put in and the excavation for them forgotten; or in wooden bridges the timber put in and the bolts left out; in pipe culverts, the pipe is allowed for and foundations or end walls for-

gotten, and there is always a tendency to omit ditches or borrow in excavation; by using a tabulated form similar to that suggested it is believed that there is less liability to leave things out and a much better opportunity to check what is done. The distribution of quantities is especially important, and the writer believes, as previously stated, that in no way will the engineer become so familiar with the effect of the details of the topography as by thoroughly following out the distribution of the quantities for each projected line. Not merely taking the quantities off the profile, but estimating the swell, amount in side ditches, etc., and showing exactly where each cut has to go, and where the material for each embankment is to come from and how much overhaul is involved.

In comparing the relative value of two or more lines, besides the estimate of cost of actual construction, a value must be given to the factors which affect the cost of operation and maintenance. The fact that a line is on the north or south side of a valley which will be warmer or colder, as the case may be, or that one route is more exposed to snowslides than another, or where the nature of the materials forming the slope of cuts is treacherous and difficult to keep up (bad clay banks, etc.), or any other circumstance similarly affecting the cost of maintenance outside of the ordinary, must be given due consideration and proper allowance made for it.

The principal causes affecting cost of operation, as far as the location is concerned, are curvature and grades. As this book is intended primarily only for students and men up to the grade of locating engineers, that is, as previously explained, the man who actually has charge of the field party, the question of determining the rate of ruling grade affecting the whole operating division is considered generally beyond his province. With the ruling grade fixed, the problem is confined (although even then it is plenty big enough) to the consideration of fixing the grade line on the profile obtained, and determining the true balance between curvature and rise and fall and possibly at times putting in a pusher grade, and the consideration of the costs of operation as affecting the location will be confined herein, within those limits.

The effect of curvature is to increase the cost of operation, due to the increased resistance to trains, thus increasing the power required to haul the train and to increase the wear and tear on the track and rolling stock. Mr. Wellington estimated that the increased cost of hauling one train daily around a 1° curve 100 ft.

long to be 43.3 cents *per year* more than for hauling the same train over a piece of straight track the same length. By daily train is meant one train daily in each direction.

It is considered that the *rate* of curvature, at any rate within the limits of ordinary railroad work, say for curves up to 10°, has no effect on its cost; that is to say, the increased cost of hauling a train around 1,000 ft. of 1° curve would be the same as around 100 ft. of 10° curve; in each case there would be 10° of central angle.

Whether these assumptions are absolutely correct or not makes little difference; they are undoubtedly as nearly correct as any estimate which can be made of the cost of work before it is done, and they can be used to avoid any large errors of judgment.

If, therefore, 10 daily trains in each direction are assumed as the probable amount of traffic, the increased yearly cost of operating the road due to 20° of curvature would be $\$0.433 \times 10 \times 20 = \$86.60$. If capital can be obtained at 5% this would justify an expenditure of $1,732 to avoid the curvature.

Thus apparently the amount available to save curvature is not very much, and also, apparently sharper curvature is little detriment, provided the central angle is not increased; but practical common sense must be exercised in this, as in using momentum grades or undulating grades. One especially important point is the matter of speed and the fact that the demand for higher speeds is growing greater all the time, and even though the road be out in the wilderness, with no immediate prospect of more than two or three trains a day, the future must be kept in mind, and reasonable though not too great allowance made for it. The right of way is bought conforming to the alignment, and future changes in this latter of any great extent generally mean the abandonment of the whole of the roadbed and the construction of a brand new piece of line.

There are other conditions of operating which cannot be actually reduced to dollars and cents, such as the easier riding of passenger trains, and consequent attractiveness to passengers on that account; less liability of collisions, etc., etc. It is generally wise, therefore, not to use a sharper curve than is absolutely necessary, and to use as little curvature as is consistent; the amount of money to be spent to avoid curvature, as indicated above, being used as a rough guide to the judgment.

If it is necessary to save money on construction, endeavor to

keep good alignment and lay out a temporary grade line, making free use of momentum grades, especially where they can afterwards be improved by the company's work trains when the money is available, which work will probably cost far less than building a whole new line.

In using momentum grades to cheapen construction on a new line, values even a little higher than those given in the table may be assumed, although thereby the engine rating, or the load the engine can haul, is thereby lessened until the improvements can be made.

In locating such a line, the line as it will be when finally put in shape must be located and grades fixed as for the final line; then with this all in shape, cheapen up the line in such a manner that the improvements can be surely carried out when time and money allows.

It may be asked, why not stiffen up the ruling grade? But it should be readily seen that with a long rise where there might be a mile or two of ruling grade, say of 0.5%, if the bulk of this at the top of the hill was on the proper 0.5% and perhaps 2,000 or 2,500 feet at the bottom on an 0.8% or 1.0%, this latter could be more or less easily raised, whereas if a 0.7% was located from the bottom to the top, it would mean an entirely different line and would have to be changed all over to reduce the grade.

The effect of grades on operating expenses comes under two headings, the effect of ruling grades to limit the weight of trains to be hauled by any particular engine over the whole operating division and the effect of rise and fall. If one terminal is say 20 ft. higher than the other and a straight grade lies between, as A and C, Fig. 2, then the rise and fall is negligible, provided there is the same amount of traffic each way, because the extra power exerted to haul the train up will be balanced by the lesser amount needed when hauling the train down, provided the rate of grade is not high enough to increase the number of trains and train crews necessary to handle the business. On the other hand, if the grade is as A B C, B being 36 ft. higher than C, and 56 ft. higher than A, the rise and fall is $\frac{36 + 56}{2} = 46$ ft., and each train which passes over the line between these points back and forth has to raise its load 46 ft. as well as haul it over the horizontal distance.

The cost of rise and fall is divided by Mr. Wellington* into three classes:

A. Rise and fall on grades so light or so situated as never to require the use of brakes or variations in the power of the engine.

B. Rise and fall on grades heavy enough to require the slight use of brakes or shutting off steam, or both, in descending, but not such as to be a serious tax upon the engine in ascending.

C. Rise and fall on maximum grades requiring the full power of the engine in ascending, with more or less use of sand, danger of slipping drivers, and the use of brakes in descending.

In the first class (A) of course are those grades which are considered under the head of momentum grades, and which can be operated as such. Referring to the diagram (Fig. 43), if a speed of 35 miles per hour is assumed as permissible and if no stops or curvature limit the speed, all the grades will be included in class A. If, on the other hand, the speed is limited to 30 miles per hour, the grade from B to C will fall in the second class (B).

The cost per foot of rise and fall (that is, 1 ft. up and 1 ft. down) in class A is, of course, nothing. In classes B and C it is estimated at $0.84 and $2.67 per foot per daily train per annum, respectively, on minor gradients, and $0.83 more on ruling gradients, or $1.67 and $3.50, respectively. Thus, in class B on minor gradients: On a road with ruling grades of 2.0%, with 50 ft. of rise and fall composed of several comparatively short stretches on grades, say, less than 1.0%, the cost of operating 10 trains per day over these grades over what it would cost to operate over a level grade would be:

$0.84 × 10 × 50 = $420, which, at 5%, would justify an expenditure of $8,400 to eliminate them.

If these same stretches were all on the ruling (2%) grade, the cost would be:

$1.67 × 10 × 50 = $835, at 5%, justifying the expenditure of $16,700.

In class C would be included short stretches of maximum grade, with conditions as noted, and the cost would be, for 50 ft. rise and fall and 10 daily trains:

$2.67 × 10 × 50 = $1,335, which, at 5%, would justify the expenditure of $26,700.

and in class C on ruling grades under the conditions noted:

$3.50 × 10 × 50 = $1,750, or an amount justifying the expenditure of $35,000 to reduce to a level grade.

These classes naturally overlap more or less, but sufficient is given so that some idea will be obtained of the values of rise and fall, which are far better than wild guessing, and which will, if

*Economic Theory, page 330.

used intelligently, come as close as it is generally possible to estimate the other values affecting the cost.

The increased cost of operation for maintaining a pusher or helper engine is variously estimated at $10,000 to $15,000 a year, which, at 5%, would justify the expenditure of $200,000 to $300,000 to keep the line on ruling grades, less the cost of operating the extra distance involved, if any, to get the lighter grade.

The effect of distance on operating expenses is naturally divided between competitive and non-competitive traffic. In the latter case of course extra distance may be a source of profit, as charges are made according to the number of miles freight and passengers are carried; in the first case, however, in the case of competitive roads (and it will always be well to bear in mind future developments), for minor changes which will not affect the wages of the train crews, Mr. Wellington* estimates the cost of operation at 3.43 cents per lin. ft. per daily train per annum, based on an assumed value of $100 per train per train mile for operating expenses.

Thus for 10 trains per day the cost per foot is 34.3 cents, which, capitalized at 5% = $6.86.

Thus, in comparing two or more lines, the results may be summarized as follows, the temporary structures being capitalized at a figure which will insure their renewal in ten years, ten trains daily in each direction being assumed as the probable traffic, and capital being assumed to be available at 5%, which is somewhat low:

	Data		Capitalized Value	
	Line A.	Line B.	Line A.	Line B.
Total Length	21,356 ft.	22,848 ft.	....	$10,235.12
" Degrees, curve	78°	123°	$337.74	532.59
" Rise and fall, Class B, at say $1.00 per ft. per train.	56 ft.	38 ft.	560.00	380.00
" Rise and fall, Class C, at say $3.00 per ft. per train.	36 ft.	42 ft.	1,080.00	1,260.00
Cost of Construction, permanent	$108,750.00	$93,245.00	108,750.00	93,245.00
Cost of Construction, temporary, to be renewed in 10 years	$23,840.00	$15,780.00	47,680.00	31,560.00
Right of Way, (at 25 cents running foot)	21,356 ft.	22,848 ft.	5,339.00	5,712.00
Track Laid and Ballasted at $1.50 per lin. foot)	21,356 ft.	22,848 ft.	32,034.00	34,272.00
Fencing at 10 cents lin. foot	....	....	2,135.60	2,284.80
	....	....	197,916.34	179,481.51

* Economic Theory, p. 209.

In this particular case, which is purely hypothetical, the advantage is all apparently with the longer line and larger amount of curvature, the advantages of Line A in this respect being more than offset by the lower cost of construction of Line B. If, say, half the traffic was non-competitive, there would be a difference of about $5,000 more in favor of B, as the difference in distance, 1,492 ft., is capitalized for the whole of the ten trains.

It will be noted that the capitalized value of the temporary structures is placed at twice their original value. Theoretically it should be 2.227 times as much, as the compound interest on $1.227 will just amount to $1.00 at the end of 10 years at 5%. The capital required to provide for renewal every 10 years is therefore $1.227 for every dollar of the cost of the structure, and to this must be added the original cost. It will generally be near enough, however, for purposes of estimates, to assume the capitalized value at twice the original value. The life of structures is uncertain; in any event, they are generally repaired a piece at a time, and it is very little use to attempt to calculate too closely for what may happen 10 years hence.

Considerable caution should be exercised in using any of these figures and results, or any others, *solely as figures.* The whole situation must be studied on the ground and in the light of the character of the road and the business it is expected to do.

In estimating the size of openings required for waterways, the conditions as they exist on the ground must be carefully studied. Some evidences can usually be found indicating the height of the highest water; and the area of the cross section of the stream up to that elevation is the surest guide to the area of waterway required; any existing structures near the line of the road may help, if they have been in place long enough, to show that a larger structure than that in place is not necessary; as an example, however, of the varying judgments in this respect may be cited an instance near New York City of four structures on the same stream, all within a length of half a mile; furthest up stream was a highway bridge with two 70-ft. spans; next below, a four-track railway crossing, with two 40-ft. masonry arches; immediately below this, a highway bridge of 50-ft. span, deck girders, and below this the oldest structure of all, a simple wooden truss of 25-ft. span, on dry rubble abutments, which latter opening had carried

all the water for at least fifty years with no trouble whatever, as far as could be ascertained.

Railroads are usually liberal in proportioning waterways, but on roads with more or less light traffic it is often economy to stand the expense of an occasional washout rather than build all the openings to take care of an occasional cloudburst or exceptional flood. Any formulæ for calculating area of waterways required, from area of watershed, depend on judgment as to amount and time of run off; a judgment based on the actual area of the waterway at highest water mark at the point where the structure is to be built is far better than anything else.

Box Culverts may be designed in either of the two methods shown (Fig. 63); in either case if the length be taken as the total

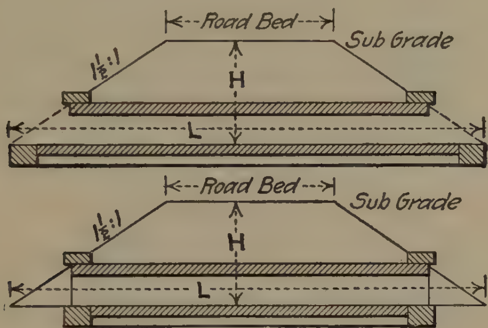


FIG. 63.

distance between the toes of slopes at the elevation of the bed of the stream, due allowance being made for skew, the quantities obtained by multiplying the sectional areas given below by this length will be practically the same for either design on account of differences of head walls. The areas given are the standards of the B. & O. R. R.:

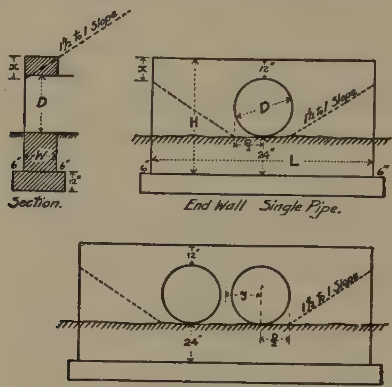
Clear Opening.	Sectional Area, Square Feet.	
	Single.	Double.
2 × 3	31	47
3 × 3	33	51
3 × 4	34	64
4 × 4	46	68
4 × 5	59	83

Vitrified Pipe Culverts.—Practically the only size used on railroad construction should be 24″. Less than that is too small for any opening, and more than that too large for vitrified pipe under

a railroad track. Not less than 5 ft. of good fill, carefully placed, should be allowed above the pipe.

Vitrified pipe will probably need a concrete bed, which will average probably 0.2 cu. yds. per lin. ft. of pipe. In any event, proper allowance must be made for providing a compact foundation. The length of pipe culverts with end walls as shown (Fig. 64) is equal to

Width of road bed + 3 times height from subgrade to top of pipe.



End Wall Double Pipe.
x variable according to width of Wall (W).
D inside diameter of Pipe.
y = 15" for 24" pipe, 21" for 36" pipe, 30" for 48" pipe.
FIG. 64.

End walls for vitrified pipe culverts should be about the same as for cast-iron pipe. It is often wise to allow for a few square yards of paving at the lower end of the pipe.

Cast Iron Pipe Culverts are usually limited to 24″ and 36″ pipe, possibly 48″, but this latter is rather too heavy to handle. It must be remembered that culverts have to be completed before the grading can be done, and supplies must be hauled by teams.

24″	pipe will weigh about	250	lbs. per lin. ft.
36″	"	400	"
48″	"	700	"

These weights are for extra heavy; 20% may be deducted for lighter weight pipe, which, however, should seldom, if ever, be used on railroad work.

The form of end walls shown (Fig. 64) may be modified by turning the ends at 60° to form wing walls at the up stream end.

This will have little effect on the quantities involved, however. In actual construction, a coping would probably be formed by projecting the top; but none of these details will materially affect the quantities for an estimate.

The following tables gives the quantities required for one end wall as shown (Fig. 64).

Size of Pipe	SINGLE							DOUBLE						
	Foundation			Wall			Cubic Yds. in One Wall	Foundation			Wall			Cubic Yds. in One Wall
	W ′ ″	L ′ ″	H ′ ″	W ′ ″	L ′ ″	H ′ ″		W ′ ″	L ′ ″	H ′ ″	W ′ ″	L ′ ″	H ′ ″	
24″	2.6	9.0	1.0	1.6	8.0	5.0	3.1	2.6	11.6	1.0	1.6	10.6	5.0	3.8
36″	3.0	12.6	1.0	2.0	11.6	6.0	6.0	3.0	16.0	1.0	2.0	15.0	6.0	7.4
48″	3.6	16.0	1.0	2.6	15.0	7.0	10.6	3.6	21.0	1.0	2.6	20.0	7.0	13.4

Wooden Culverts.—These are usually built so that when the timber gives out they can be replaced by cast-iron pipe by simply

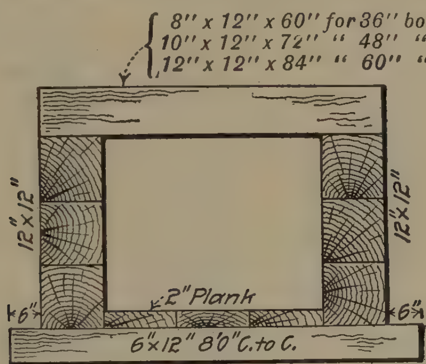


FIG. 65.

pulling the pipe through, and are therefore made about 1 ft. larger each way than the diameter of the pipe which may be used, as, for 24″ pipe, the wooden culvert will be 36″ square, inside diameter. Their length should be estimated from toe to toe of slope, as for masonry box culverts. The three sizes will average, per running foot, about as follows:

Inside Dimensions.	Feet, Board Measure, Per Running Foot.
36″	124
48″	170
60″	220

based on similar sections, as shown (Fig. 65).

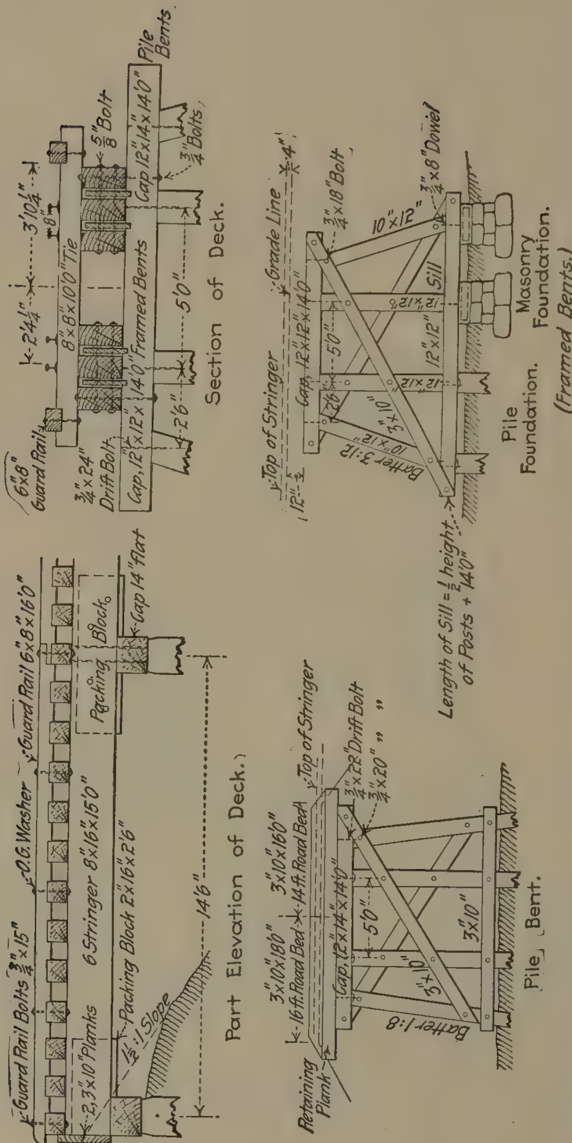


FIG. 66. TYPICAL PILE AND FRAMED TRESTLE, MIDLANL VALLEY R. R. STANDARD, F. A. MOLITOR, CH. ENGR.

Pile and Frame Trestles.—General type (see Fig. 66).—The deck of either class of structure will be practically the same; a typical structure for heavy traffic will contain the following timber in the deck for 14′ 9″ spans:

		Ft., B. M.
2 Guard rails............	6″ × 8″ × 14.75′	118
12 Ties....................	8″ × 8″ × 10′	640
6 Stringers...............	8″ × 16″ × 15′	960
4 Packing blocks.........	2″ × 16″ × 5′	53
1 Cap....................	12″ × 14″ × 14′	196
Total ft., B. M., in deck, 1 span 14.75 ft. =		1,967

or an average of 133 ft. B. M. per running foot in the deck. The iron in this will be about as follows:

		Approximate weight, in lbs.
8 Guard rail bolts...........	¾″ × 15″	17.9
8 Packing bolts.............	⅝″ × 35″	26.3
4 Anchor bolts.............	¾″ × 31″	16.9
4 Drift bolts................	¾″ × 22″	10.9
32 Packing washers..........	⅞″ × 4″	64.0
40 O. G. washers.............	⅝″ × 3½″	48.0
16 Line spikes................	½″ × 14″	15.7
Total weight, wrought-iron, 1 span, 14.75 ft., =		199.7

or an average of about 13.6 per running foot of the deck. To these amounts must be added 500 ft. B. M. timber for the extra end bent and 15 lbs. wrought iron for same.

The following table gives the timber and number of bolts for each bent for sash and sway bracing for pile bents above 8 ft.:

3″ × 10″ bracing.
¾″ × 18″ bolts (each weighing, with two washers, 5 lbs.).

Height of bent, grade line to ground line, ft.	Ft., B. M., in both sash and sway bracing, for one bent.	No. of bolts, sash and sway bracing, for one bent.
8	115	14
10	125	
12	130	
14	140	
16	150	
18	160	
20	165	
22	325	26
24	325	
26	325	
28	370	
30	370	

For frame bents, add 20% for heights above 20 ft.

For length of piling, generally allow 10 ft. penetration, 4 piles to a bent; allow length from 1 ft. above sub grade line to allow for cut-offs.

For frame trestles allow for each bent 4 sticks 12 × 12 timber, length 2 ft. less than height from sub grade to ground line, and add 1 pc. 12 × 12 for sill 14 ft. longer than half height of posts, and mud sills, if necessary, 8″ × 16″ × 4 ft., two at least under each post.

The following table gives the number of ft. B. M. in the posts and sills of frame trestles from 8 to 30 ft. high.

Height.	Ft., B. M., in posts.	Ft., B. M., in sill.	Total ft., B. M., posts and sills.
8	288	204	492
10	384	216	600
12	480	228	708
14	576	240	816
16	672	252	924
18	768	264	1,032
20	864	276	1,140
22	960	288	1,248
24	1,056	300	1,356
26	1,152	312	1,464
28	1,248	324	1,572
30	1,344	336	1,680

In Fig. 67 is shown a trestle of 5 spans, each span 14.75 ft.,

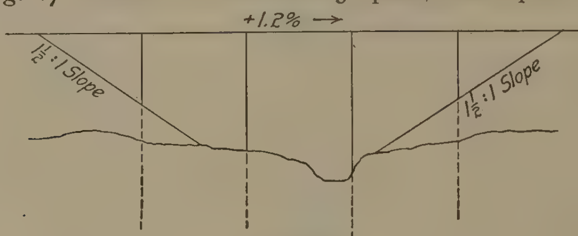


FIG. 67.

or 73.75 ft. centre to centre of bank sills, say 75 ft. over all. The total quantities in such a trestle would be calculated as follows;

For Pile Trestle.

Timber—

		Ft., B. M.
Deck. 75 × 133	=	9,975
Extra end bent		500
Bracing, 1 bent, 11	=	130
" 1 " 21	=	325
" 1 " 17	=	160
" 1 " 9	=	120
		11,210 Total ft., B. M., timber

Piling—

4 bents, 28-ft. piles, $= 4 \times 4 \times 28 = 448$ lin. ft. piling.

Wrought Iron—	Lbs.
75 lin. ft. × 13.6 =	1,020
Add four end bents,	15
Bracing: 3 bents, 14 bolts, and 1 bent, 26 bolts = 68 bolts, 5 lbs. each.	340
Total,	1,375

For Frame Trestle.

Timber—

	Ft., B. M.
Deck, 75 × 133	9,975
Extra end bent	500
1 bent, 15′ high, posts and sill	870
1 " 21′ " "	1,194
1 " 17′ " "	978
1 " 16′ " "	924
Bracing, 1 bent, 11 ft. high	130
" 1 " 21 "	389
" 1 " 17 "	160
" 1 " 9 "	125
32 mudsills, 8″ × 16″ × 4′	1,365
Total ft., B. M., timber	16,610

Wrought Iron—	Lbs.
Deck, 75 × 13.6 =	1,020
Add	15
Bracing: 3 bents, 14 bolts, and 1 bent, 26 bolts = 68 bolts, 5 lbs. each.	340
1 dowel in each post, ¾″ × 8″ = 16 dowels, 1 lb. each,	16
	1,391

Arches.—The following table, published by permission of John C. Trautwine, Jr., and taken from Trautwine's "Civil Engineer's Pocket-Book," the writer has found to give very satisfactory results for preliminary estimates for quantities in semicircular masonry arches, either for stone, brick or plain concrete.

"The quantities given include the two spandrel walls and four wings; the height in the second column is from top of keystone to bottom of foundation. The several lengths from end to end, or from face to face, of the *arch proper*. The contents for intermediate lengths may be found exactly; and those for intermediate heights, quite approximately, by simple proportion. In this table, it will be observed that *when the heights are the same in both cases,* a larger span frequently contains less masonry than a smaller one. A semicircular culvert or bridge contains less masonry than a flatter one, when the total height is the same in both cases; therefore, the first is the most economical as regards cost; but it does not afford as much area of water-way; or width of headway."

TABLE IV.

Span	Height	LENGTH, FEET 15	20	30	40	60	80	100	120	140	160	180	200
ft.	ft.	cu. yd.	cu. yd,	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.
2	5	27	32	42	52	72	92	112	132	152	172	192	212
	6	37	43	56	69	94	120	146	171	197	222	248	274
	7	49	57	73	89	122	154	187	219	251	284	316	349
	8	63	73	93	113	153	193	233	273	313	353	393	433
	10	101	116	145	175	234	291	351	410	469	527	586	645
3	5	28	34	44	54	75	96	117	138	158	179	200	221
	6	38	44	57	70	95	121	146	172	198	223	249	275
	7	49	57	73	89	121	153	184	216	247	280	312	343
	8	63	73	93	112	152	191	230	269	308	348	387	426
	10	101	115	143	172	229	286	343	400	457	514	571	628
	12	149	169	208	248	328	407	487	567	646	726	806	885
4	5	30	35	46	57	78	100	122	143	165	186	208	229
	6	38	45	58	70	96	122	147	173	198	224	250	275
	7	49	57	73	88	119	150	181	212	243	274	305	336
	8	63	73	92	111	149	188	226	264	302	340	379	417
	10	100	114	141	169	224	279	335	390	445	500	555	611
	12	147	166	204	243	319	395	472	548	625	701	777	854
	14	209	234	285	336	437	539	641	742	844	945	1047	1149
5	6	41	47	61	75	102	130	157	184	212	239	267	294
	7	52	60	76	93	125	158	191	224	257	289	322	355
	8	65	75	94	114	153	192	231	270	309	348	387	426
	10	100	114	141	168	223	277	331	386	440	495	549	603
	12	146	165	202	239	314	388	463	537	611	686	760	835
	14	207	231	280	329	427	525	623	721	819	917	1015	1113
6	7	53	62	79	96	131	165	200	234	268	303	337	372
	8	66	76	96	116	156	196	236	276	316	356	396	436
	10	100	113	140	167	220	274	327	380	434	487	541	594
	12	146	164	200	236	308	381	453	526	598	670	743	815
	14	206	219	277	325	420	516	611	706	802	897	993	1088
	16	281	311	373	434	556	679	801	923	1046	1168	1291	1413
8	7	57	67	85	104	141	178	215	252	289	326	363	400
	8	70	81	102	124	166	209	251	294	337	379	422	464
	10	104	118	145	173	228	284	339	395	450	505	561	616
	12	147	165	200	236	308	379	450	522	593	664	736	807
	14	206	230	276	323	416	510	603	696	790	883	977	1070
	16	281	310	370	430	549	669	788	908	1027	1146	1266	1385
	18	367	405	480	554	704	854	1003	1153	1302	1452	1602	1751
10	8	74	85	108	131	176	221	266	311	357	402	447	492
	10	107	121	150	179	236	294	351	408	466	523	581	638
	12	148	166	201	236	306	377	447	518	588	658	729	799
	14	207	229	275	321	412	504	595	686	778	869	961	1052
	16	280	309	368	426	542	659	775	891	1008	1124	1241	1357
	18	366	402	475	548	693	839	984	1129	1275	1420	1565	1711

TABLE IV.—Continued.

Span	Height	LENGTH, FEET 15	20	30	40	60	80	100	120	140	160	180	200
ft.	ft.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.	cu.yd.
12	10	110	125	154	183	242	301	359	418	476	535	594	652
	12	151	168	204	239	310	381	452	523	594	665	73[illegible]	807
	14	206	228	272	317	405	493	581	669	758	846	934	1022
	16	279	306	362	418	529	640	751	862	974	1085	1196	1307
	18	364	399	469	540	680	820	960	1100	1241	1381	1521	1661
	20	470	512	598	684	855	1026	1197	1368	1540	1711	1882	2053
15	12	162	182	222	262	342	422	502	583	663	743	823	903
	14	215	239	286	333	427	522	616	711	805	899	994	1088
	16	285	313	370	427	541	654	758	882	996	1110	1223	1337
	18	369	404	474	545	686	826	967	1108	1249	1390	1530	1671
	20	473	515	600	685	855	1024	1194	1364	1534	1704	1873	2043
	22	595	646	748	850	1054	1258	1462	1666	1870	2074	2278	2482
20	14	237	264	317	371	478	586	693	801	908	1015	1123	1230
	16	304	335	397	458	582	706	829	953	1076	1200	1324	1447
	18	381	416	486	556	697	838	978	1119	1259	1400	1541	1681
	20	479	520	601	682	844	1007	1169	1332	1494	1656	1819	1981
	22	598	646	741	837	1028	1220	1411	1603	1794	1985	2177	2368
	24	739	795	908	1021	1247	1473	1699	1925	2151	2377	2603	2829
25	16	327	360	428	496	631	766	901	1036	1172	1307	1442	1577
	18	403	441	517	594	746	898	1050	1202	1355	1507	1659	1811
	20	500	543	629	715	887	1059	1231	1403	1575	1747	1919	2091
	22	614	663	760	857	1051	1246	1440	1635	1829	2023	2218	2412
	24	751	807	919	1031	1255	1479	1703	1927	2151	2375	2599	2823
	26	909	974	1104	1234	1494	1754	2014	2274	2534	2794	3054	3314
	28	1085	1160	1310	1460	1760	2060	2360	2660	2960	3260	3560	3860
35	22	685	743	859	975	1207	1439	1671	1903	2135	2367	2599	2831
	24	817	880	1007	1134	1388	1642	1896	2150	2404	2658	2912	3166
	26	969	1033	1181	1309	1585	1861	2137	2413	2689	2965	3241	3517
	28	1130	1205	1356	1507	1809	2111	2413	2715	3017	3319	3621	3923
	30	1327	1408	1571	1734	2060	2386	2712	3038	3364	3690	4016	4342
	32	1549	1639	1820	2001	2363	2725	3087	3449	3811	4173	4535	4897
	35	1946	2054	2271	2488	2922	3356	3790	4224	4658	5092	5526	5960
50	30	1494	1594	1795	1996	2398	2800	3202	3604	4006	4408	4810	5212
	32	1711	1819	2035	2251	2683	3115	3547	3979	4411	4843	5275	5707
	34	1956	2071	2302	2533	2995	3457	3919	4381	4843	5305	5767	6229
	36	2228	2350	2597	2844	3338	3832	4326	4820	5314	5808	6302	6796
	38	2519	2650	2913	3176	3702	4228	4754	5280	5806	6332	6858	7384
	40	2835	2975	3255	3535	4095	4655	5215	5775	6335	6895	7455	8015
	42	3197	3347	3647	3947	4547	5147	5747	6347	6947	7547	8147	8747
	45	3818	3991	4337	4683	5375	6067	6759	7451	8143	8835	9527	10219
	50	5063	5281	5717	6153	7025	7897	8769	9641	10513	11385	12257	13129

Steel Bridges.—The following formulæ are used for approximate estimates of weight of steel bridges on the B. & O. R R. for single track. For each additional track add 90%:

Deck	spans	$(9 \times \text{span}) + 300$ lbs.	= weight per lin. ft.
Through	spans	$(9 \times \text{span}) + 550$ lbs.	= weight per lin. ft.
Truss	spans	$(8 \times \text{span}) + 400$ lbs.	= weight per lin. ft.

Table V. gives dimensions, weights, etc., standard steel bridges, C. O. & G. R. R., and may be taken as typical of first-class construction in the West for heavy engines.

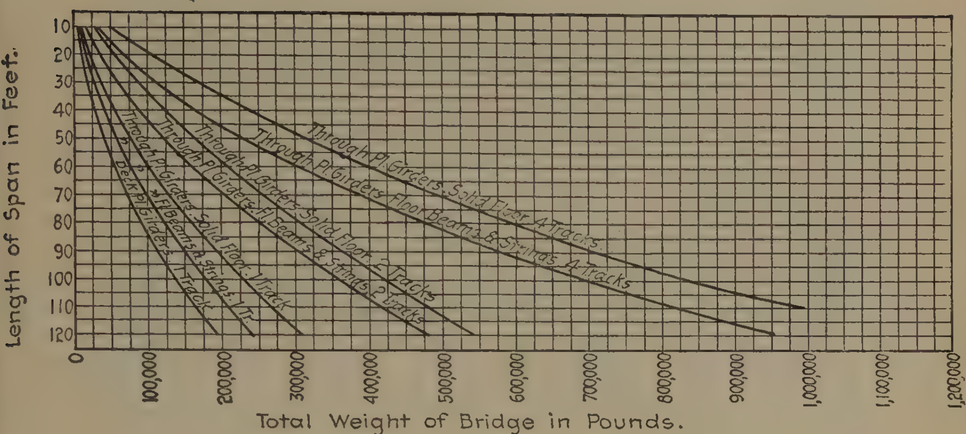
TABLE V.—*Choctaw, Oklahoma & Gulf Railroad. Description and Weights of Standard Steel Bridges.*

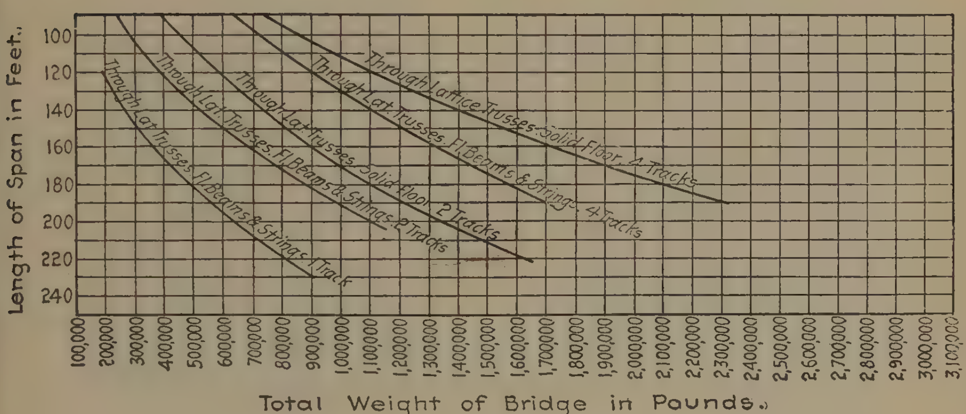
Span, ft.	Description.	Base rail to top of masonry.	Weight.	Center to center of truss.	Distance between back walls.
30	Deck Pl. Gir.	4′ 5¾″	11,750	9′ 0	31′ 0
	Thro' "	2′ 3 9-16″	23,400	16′ 0	30′ 8
40	Deck "	4′ 11¾″	18,920	7′ 0	41′ 0
	Thro' "	2′ 3⅝″	34,000	16′ 0	40′ 8
50	Deck "	5′ 11¾″	29,350	7′ 0	51′ 0
	Thro' "	2′ 3 11-16″	48,700	16′ 0	50′ 8
60	Deck "	6′ 11¾″	39,400	7′ 0	61′ 0
	Thro' "	2′ 3¾″	64,100	16′ 0	60′ 8
70	Deck "	7′ 11¾″	50,700	7′ 0	71′ 0
	Thro' "	2′ 3¾″	78,400	16′ 0	70′ 8
80	Deck "	10′ 3½″	74,900	7′ 0	81′ 0
	Thro' "	3′ 7⅝″	105,000	16′ 0	80′ 8
90	Deck "	11′ 3½″	92,000	7′ 0	91′ 0
	Thro' "	3′ 7⅝″	126,000	16′ 0	90′ 8
100	Deck Lat.	12′ 10 7-16″	98,300	9′ 0	103′ 0
	Thro' "	2′ 10¾″	131,500	16′ 0	103′ 2
125	Deck "	25′ 9 1-16″	174,700	13′ 0	128′ 6
	Thro' "	5′ 3¼″	164,500	16′ 0	129′ 0
150	Deck Pin	36′ 6⅛″	224,500	16′ 0	154′ 0
	Thro' "	5′ 3¼″	224,500	16′ 0	154′ 0
250	Thro' "	5′ 11⅛″	637,600	16′ 6	254′ 8⅜

Figure 68 is a diagram of approximate total weights of steel bridges, New York Central & Hudson River R. R., January, 1902.

Masonry Abutments and Retaining Walls.—Figures 69, 70 and 71 show diagrams of standard abutments, piers and retaining walls, N. Y. C. & H. R. R., from which quantities may be readily taken off for approximate estimates.

Tunnels.—Tunnel excavation may be roughly estimated at \$4.00 to \$7.00 per cu. yd. and the number of cu. yds. per lin. ft. 15 cu. yds. for single track and 25 cu. yds. for double track tunnel. The higher cost should be used for preliminary estimates. The cost of tunnels in soft ground will be at least as high as in





N.Y.C. & H.R.R.R.

Leased and Operated Lines.

Approximate Total Weights of Steel Railroad Bridges.

Specifications of 1900.

New York, Jan. 1st 1902. *Office of Chief Engineer.*

Note: The weights include the Steel work only.

W. Wilgus.
Chief Engineer.

FIG. 68.

rock on account of cost of supports during excavation, and cost of lining must be added. For concrete lining $8.00 to $10.00 per yard should be estimated.

Cattle Guards may be estimated at $20.00 to $25.00 each for first-class construction oak surface guards.

Water Tanks with a capacity of 50,000 gals., with stone foundations for posts, first-class timber construction, cost about $1,000 each erected.

Cost of Equipment.—The value of the equipment of all the railroads in the United States, as given in the report of the U. S. Interstate Commerce Commission, shows an average of about $3,600 per mile. The cost of equipment for new roads may be roughly estimated at about $5,000 per mile. The following approximate costs of locomotives of various sizes have been kindly furnished by the Baldwin Locomotive Works, July, 1906:

Weight of engine.	Cost: Passenger.	Cost: Freight.
40 tons	$8,000	$8,400
60 "	10,000	10,600
80 "	15,000	13,400
100 "	18,000	16,000
120 "	.....	20,000
140 "	.....	22,000

The following values of passenger and freight cars are taken from the report of the New York State R. R. Commission for 1905, and will give at least an approximate idea of their value:

Parlor and chair cars	$10,000 to	$12,000
1st class passenger coach	5,000 to	8,000
2d class passenger coach	3,500 to	6,000
Baggage, mail and express cars	2,500 to	4,000
Combination passenger and baggage	3,000 to	6,000
Freight cars:		
Box and stock cars	400 to	600
Coal cars	500 to	700
Flat cars	200 to	400
Caboose	300 to	1,000
Service cars	500 to	800

The following tables, in lieu of better data, will give at least an idea of the costs of various classes of railroad construction, it being understood, of course, that these are liable to fluctuations, according to locality, time, cost of labor and materials, etc.

Table VI. shows the items and approximate contract prices on a complicated grade crossing elimination in a large city in Eastern New York State in 1905, and gives a good idea of what an estimate of such a piece of work may involve.

TABLE VI.

	Unit.	Estimated cost per unit.
Removal of old buildings, lump sum		....
Excavation—Old masonry	Cu. yds	1.00
" In water	"	1.00
" Solid rock	"	1.50
" Borrowed	"	0.21
" Unclassified	"	0.35
Piling in permanent work below cut-off	Lin. ft	0.30
Yellow pine timber in permanent work	M. F. B. M	35.00
Spruce timber in permanent work	"	32.00
Hemlock timber in permanent work	"	27.50
Yellow pine timber in temporary work, left in by order of engineer	"	25.00
Spruce timber in temporary work, left in by order of engineer	"	20.00
Concrete, Class A	Cu. yds	7.50
" " B	"	5.00
" " C	"	10.00
" " D	"	4.50
" Paving, Class A	Sq. ft	0.15
" " " B	"	0.17
" " " C	"	0.20
" Curbs, standard	Lin. ft	0.50
Farm drain tile, 4″, in place, including back filling	"	0.05
Vitrified sew'r pipe, 6″, in pl., inc. back filling.	"	0.20
" 8″, "	"	0.25
" 10″, "	"	0.38
" 12″, "	"	0.48
" 15″, "	"	0.70
" 18″, "	"	0.85
" 20″, "	"	1.15
" 24″ "	"	1.60
Brick masonry in sewer manholes	Cu. yds	10.00
Manholes, complete, including iron	Each	40.00
Brick sewers, 4′ 6″x3′ 0″	Lin. ft	6.00
" 4′ 3″x2′ 10″	"	5.75
" 4′ 0″x2′ 8″	"	5.50
" 3′ 6″x2′ 4″	"	5.00
" 2′ 6″	"	4.50
Catch basins, complete, including iron	Each	67.50
Flush tanks, relaid	"	40.00
" new	"	40.00
Straight cast iron water pipe, delivered, but not laid	Net ton	30.00
Special cast iron water pipe, delivered, but not laid	"	60.00
Straight cast iron gas pipe, delivered, but not laid	"	30.00
Special cast iron gas pipe, delivered, but not laid	"	60.00
Standard gas pipe fence, in place	Lin. ft	0.75
Laying 4″ cast iron pipe, including back filling.	"	0.18

TABLE VI.—CONTINUED.

Laying 6″ cast iron pipe, including back filling	Lin. ft.	0.21
" 8″ " "	"	0.26
" 10″ " "	"	0.35
" 12″ " "	"	0.40
" 16″ " "	"	0.60
" 18″ " "	"	0.75
" 20″ " "	"	0.90
" 24″ " "	"	1.25
" 30″ " "	"	1.75
3″ Galvan. pipe, wrought iron, with fittings.	"	0.35
4″ Wrought iron pipe, with fittings	"	0.35
3½″ Iron pipe for conduits	"	0.30
3″ Cocks and boxes for water pipe	Each	7.75
6″ "	"	11.85
12″ "	"	36.25
20″ "	"	75.00
Double nozzle fire hydrants and appurtenances.	"	22.50
Resetting hydrants and appurtenances	"	27.50
6″ Blow-offs	"	11.85
4″ Cocks and boxes for gas pipes	"	7.90
6″ "	"	10.60
8″ "	"	17.35
10″ "	"	25.00
12″ "	"	31.50
16″ "	"	55.50
20″ "	"	74.50
30″ "	"	212.50
Line and side drips, placing only	"	....
Wrought iron	Lb.	0.03
Cast iron (except cast iron pipes)	"	0.025
Roebling galv. netting No. 8 wire, 1″x2″ mesh.	Sq. ft.	0.07
Clinton galv. netting No. 8 wire, 3″x8″ mesh.	"	0.03
Pavements, cobble, relaid	Sq. yd.	0.25
" " new	"	0.75
" Macadam	"	1.00
" Brick, relaid	"	1.75
" " new	"	2.40
" Stone block, new	"	2.25
" " relaid	"	1.00
" Asphalt, new, inc. guarantee	"	2.25
Flagging, new, in place (according to requirements of proper city authorities)	"	0.20
Flagging, retrimmed and relaid	"	0.07
Curbing, redressed and relaid	Lin. ft.	0.40
Curbing, new, in place (according to requirements of proper city authorities)	"	0.80
Sidewalks, new, brick	Sq. ft.	0.08
" relaid, brick	"	0.03

Table VII. gives actual contract prices on a similar class of work near Boston in 1903, first-class masonry in this case being only dimension stone; second-class masonry being ordinary ashlar, including backing and 4-ft. foundation.

TABLE VII.

Earth excavation	$0.25	Cu. yd.
Earth excavation under water	0.75	"
Rock excavation	1.00	"
100 ft. overhaul in excess of 1,000 ft.	⅝c.	"
First-class masonry, laid in Rosendale cement	21.50	"
Second-class masonry, laid in Rosendale cement	7.25	"
Third-class masonry, laid in Rosendale cement	4.95	"
Fourth-class masonry	4.00	"
Concrete made with Rosendale cement	4.50	"
First-class masonry, laid in Portland cement	22.00	"
Second-class masonry, laid in Portland cement	7.75	"
Third-class masonry, laid in Portland cement	5.45	"
Concrete made with Portland cement	5.25	"
Brick work	20.00	1,000
Enameled brick, laid	100.00	"
Yellow pine timber in the completed work	38.00	1,000 B. M
Spruce timber in the completed work	30.00	"
Wrought iron in the completed work	0.04½	Lb.
Cast iron in the completed work	0.04	"
Spruce piles in the completed work	0.15	Lin. ft.
Oak piles in the completed work	0.18	"
Chestnut piles in the completed work	0.15	"
Loading, carting and placing earth, which has previously been unloaded by and from railroad company's cars, measured in place where finally deposited	0.18	Cu. yd
Waterproof covering for shedding water	0.75	Sq. yd.
Waterproof covering for deep inclosures	0.90	"
Granite block pavement	1.75	"
6″ Macadam pavement	0.45	"
8″ Macadam pavement	0.55	"
Trinidad asphalt pavement	2.75	"
Sicilian asphalt pavement	2.75	"
Gravel surfacing	0.25	"
Tar concrete sidewalks	0.70	"
Cobble stone gutters	0.40	"
Granolithic pavement	2.00	"
Cross walks	4.50	"
Curb on edge stone, in place	1.10	Lin. ft.
13″x8″ stone step, in place	1.85	"
11″x8″ stone step, in place	1.75	"
Manholes, complete	40.00	Each.
Catch basins, complete	80.00	"
6″ sewer pipe, laid, inc. excavation and back filling	0.65	Lin. ft.
8″ " " "	0.75	"
10″ " " "	0.90	"
12″ " " "	1.15	"
15″ " " "	1.40	"
18″ " " "	1.65	"
20″ " " "	1.85	"
24″ " " "	2.00	"
Granite block pavement, taken up and relaid	0.50	Sq. yd.
Cobble stone pavement, taken up and relaid	0.40	"
Macadam pavement, taken up and relaid	0.35	"
Cross-walks, taken up and relaid	0.50	"
Curb or edge stones, taken up and relaid	0.50	Lin. ft.
Catch basins, taken up and relaid, including excavations and back filling	80.00	Each.
Manholes, taken up and reset	40.00	"

For sewer pipe, taken up and relaid, same prices as above for new sewers.

Table VIII. shows prices used on the extensions of the C. O. & G. R. R. in 1902 for preliminary estimates, and are probably fairly representative for new construction in the Southwest.

TABLE VIII.

1. Grubbing and clearing	$40.00	per acre.
2. Earth excavation	0.16	per cu. yd.
3. Loose rock excavation	0.45	"
4. Solid rock excavation	0.75	"
5. For hauling excavation into embankment, over 500 ft. free haul; for each additional 100 ft	0.01½	"
6. Excavation under water	1.00	"
7. First-class masonry	11.00	"
8. Second-class masonry	9.00	"
9. Rubble masonry, laid in natural cement	5.50	"
10. Rubble masonry, laid dry	3.00	"
11. Concrete in Portland cement	12.00	"
12. Concrete in natural cement	10.00	"
13. Paving and slope wall	3.00	"
14. Rip-rap	1.00	"
15. Overhaul on masonry, beyond the first 2 miles free haul	1.00	each cu.yd.per mile
16. Oak or pine timber in foundations	30.00	per 1,000 ft. B. M.
17. Native pine timber in pile and framed structures	32.00	"
18. Long leaf pine timber in pile and framed structures	35.00	"
19. Timber in box and log drains	30.00	
(Prices for all the above timber to include all iron work.)		
20. Oak piles driven and cut off	$0.30	per lin. ft.
21. Oak piles in foundations	0.40	"
22. Timber in road crossings	0.20	per 1,000 ft. B. M.
Vitrified culvert pipe, in place—		
23. 18″, in place	2.50	per lin. ft.
24. 24″, in place	3.50	"
Cast iron pipe—		
24″, in place	11.25	"
36″, in place	20.00	"
48″, in place	32.25	"

R. R. Construction in Mexico.—The following statement was made up by the writer in January, 1900, at the close of the construction of the Chihuahua & Pacific R. R., and can be used as the approximate cost of railroad construction in Northern Mexico. The prices are probably a little low, rather than otherwise, and are in Mexican currency, equal to approximately half as much in U. S. gold:

TABLE IX.

Grubbing and clearing (light)	$0.01	Square meter.
Solid rock excavation	1.30	Cubic meter.
Loose rock excavation	.65	"
Hard pan excavation	.40	"

TABLE IX.—Continued.

Earth excavation	$0.22	Cubic meter.
Overhaul per cub. m. per 20 m. in excess of 150 m.	.05	"
Masonry, laid in lime mortar, first class; includes all dimension stone, such as arch sheeting, coping, bridge seats, parapet walls, etc.	30.00	"
Ashlar masonry	15.00	"
Rubble masonry	9.00	"
Dry rubble	5.00	"
Overhaul on stone, per cub. m. per kilometer in excess of 1 kilometer	1.00	"

The above is based on the following prices for labor:

Day laborers*	$1.00 per day
Gang foremen	$1.50 to $2.00 per day and board.
General foremen	3.00 to 6.00 "
Blacksmiths	3.00 to 4.00 "
Commissary clerks	3.00 "
Masons and stonecutters	2.00 to 4.00 "
Wagon and six mules	6.00 per day.
Each additional mule	1.00 "
Lime delivered on work	1.00 to $1.25 per 100 lbs.
Portland cement at railhead	11.00 per barrel.

There is (or was at that time) a very heavy duty on dump carts, scrapers, harness and tents coming into Mexico. The concession for the railroad admitted free of duty all materials used *in* the construction of the railroad, but not *for* the construction.

Standard food supplies cost about as follows in Chihuahua; add about 40 cents per ton per kilometer for transportation beyond railhead:

Beef (native, delivered)	$0.25 per kilo.
Corn	3.25 per hectolitre.
Hay	40.00 per ton.
Flour	6.00 per 100 lbs.
Coffee (Mexican)	.50 per kilo.
Sugar	.25 per kilo.
Beans	.07 per kilo.
Kerosene	.80 per gallon.

Cost of resident engineer party in charge of 25 to 30 kilometers of construction:

Camp outfit $2,500

Running Expenses.

	Per month.
Salaries	$900
Camp expenses	125
Supplies from headquarters	275
	$1,300

*(Note.—It cost the contractors on this work—and this will apply largely to any work in South and Central America, as well as many parts of the United States—probably $10,000 to $15,000 for bringing laborers from other parts of the country, owing to scarcity of labor.)

Track.—The cost of track per mile may be estimated somewhat as follows for ordinary construction:

Ballast, $1,500 to $3,500 per mile, say		$2,000
Ties, 2,640, at 40c		1,056
Rails, 65 lbs. per yard, 104 tons, at $25		2,600
Angle bars, 352 pairs, at 21 lbs. per pair =	7,392 lbs.	
Spikes, 4 to each tie =	5,600 lbs.	
Track bolts, 6 to each joint = 2,112 bolts =	2,112 lbs.	
	15,104 lbs., at 2c	302
Track laying		500
Surfacing for first 12 months		500
		$6,958

It is quite common to leave the ballasting for a year or two to let the embankments settle; otherwise the filling to bring the track up to grade in sags has to be practically all ballast.

The following estimate is based on the summary (Fig. 62), and is in the form usually submitted on the C. O. & G. R. R.—track, telegraph line, and fencing being omitted and supplied in the chief engineer's office.

Reno Extension, Miles 68–77 inclusive.
Total Cost and Data—Estimate from Final Location.

	Unit.	Price.	Quantity.	Cost.
Clearing and Grubbing	acre.	$40.00	53	6,120.00
Earth Excavation	cu. yd.	.16	251,598	15,095.88
Loose Rock "	"	.45	31,068	13,980.60
Solid " "	"	.75	72,070	54,052.50
Wet "	"	1.00	802	802.00
Borrow	"	.16	18,759	3,001.44
Masonry, 1st Class	"	11.00	86	946.00
2d "	"	9.00	1,230	11,070.00
Rubble in Cement	"	5.50	345	1,897.50
Hard Pine Timber	M ft. B. M.	35.00	285,183	9,981.41
Oak Piling	lin. ft.	.30	1,835	550.50
Steel in Bridges	lbs.	.04	2,832,000	113,280.00
Cast-iron Pipe, 24 in.	lin. ft.	11.25	2,376	26,730.00
" " 36 "	"	20.00	1,152	23,040.00
				$280,547.83
Add 10%				28,054.77
Total cost				$308,602.60
Total Length				10 miles
Average Cost per Mile				$30,860.00
Total Degrees Curve				387°
" Length Tangent				36,380 ft.
Per cent. on Tangent				69%
Maximum Curve				4°
" Grade				0.5%
Total Rise and Fall				103 ft.
" Length Temporary Bridging				1,254 ft.

Cost of Surveys.—It is commonly stated that the cost of surveys for railroad location in the United States averages $100 per mile, and varies from, say, $50 to $150. This is probably correct when applied to the most common methods and where comparatively high rates of ruling grade are used. It has seldom been customary to complete the records of the survey in the manner set forth herein; it is the writer's contention, however, that all such surveys should be carried through to the point where everything is ready for construction, in the shape of maps and profiles, except the detail plans of structures, and that information of the character of all excavations be obtained by borings or soundings and clearly set forth.

Surveys for a 0.5% line through a so-called 1.0% country entail many more miles of preliminary in proportion to located line than where the "grade is made to fit the country," which generally means the grade which involves the least work on the surveys and small cost of construction, irrespective of the future operation. To determine the lowest economical rate of grade and to locate *the best line the country affords* means a great deal of work to eliminate the *other* lines which the country affords, on any of which it is possible to build some kind of a railroad, and even when the best line is found, to study every detail and work out the small refinements of line and grade which will bring the final cost of the completed line to the lowest point, means time and money for the surveys; but, as has been truly said, "excavations can be made much more cheaply by the transit in skilful hands than with a steam shovel."

The following tables show in detail the costs of surveys conducted practically in accordance with the methods outlined herein; the comparatively large amount of preliminary line run will be noted, as also the amount charged against this line for office work in the main office, which was largely for right-of-way maps, final profiles, checking of estimates, etc., and supervision charges, which are often forgotten in calculating the costs of surveys.

The length of the final located line in this instance was 179 miles, and the work was divided between four parties. The country was similar to that described by the writer, that is, long rolling country, rather badly broken up, the line running across the drainage, necessitating the exploration of a wide range of

country on either side of the proposed route. The average quantity of grading per mile was about 100,000 cu. yds., maximum grade, 0.5%, maximum curve, 2°; there was 19% of the line on curve. The writer is especially indebted to Mr. Beard for this information and notes on the same. The work was done in 1902.

There are various things to be taken into consideration in judging the fluctuations in the cost of these surveys. The preliminary location by Party No. 1 was over a severe country, and

TABLE X.

Field preliminary expense for 563 miles	$14,628.97
Field preliminary expense per mile	25.98
Field location expense for 179 miles	12,597.92
Field location expense per mile	70.38
Locating Party No. 1: Expense on preliminary, incident to above location and including preliminary and location of 9 miles	2,478.02
Office expense charged to above	6,446.08
Total cost of preliminary and location 188 miles	$36,150.99
Total cost per mile	$192.30

PRELIMINARY LINES.

	Party No. 1. July 5th to October 1st.	Party No. 2. July 22d to October 20th.	Party No. 3. August 1st to November 19th	Party No. 4. September 21st to October 21st.
	87 days.	90 days.	111 days.	30 days
Miles run and topography taken	145.8	166.3	164.1	23.2
Miles run, no topography taken	39.3	....	16.0	3.6
Total miles preliminary run	185.1	166.3	180.1	31.8
Total number payroll days	1,380	1,323	2,033	635
Average daily number of men	15.9	14.7	18.3	21.2
Average miles per day per party	2.12	1.85	1.62	1.06
Total cost of subsistence	$513.18	$646.42	$763.53	$371.47
Average daily cost subsistence per man	$0.37	$0.49	$0.38	$0.58
Relative cost percentage to lowest man subsistence	100	133	103	157
Total payroll cost (except teams)	$2,502.55	$2,683.22	$3,381.56	$1,055.55
Average daily pay per man	$1.81	$2.03	$1.66	$1.66
Total cost for teams	$522.00	$560.23	$768.55	$386.15
Daily cost for teams	$6.00	$6.22	$6.92	$12.87
Contingencies	$88.48	$112.96	$91.84	$125.73
Total cost of party	$3,629.96	$4,002.82	$5,057.96	$1,938.23
Daily cost of party	$41.72	$44.48	$45.57	$64.61
Daily cost per man	$2.63	$3.03	$2.49	$3.05
Cost per mile	$19.61	$24.07	$28.08	$60.95
Relative percentage to lowest man per mile	100	123	143	311

TABLE X.—Continued.

LOCATED LINES.

	Party No. 1.	Party No. 2.	Party No. 3.	Parties Nos. 2 and 3 Combined.	Party No. 4.
	65 days.	37 days.	8 days.	48 days.	66 days.
Miles located	56.0	37.8	7.6	42.6	39.2
Total number payroll days	1,400	709	151	1,498	1,283
Average daily number of men	21.5	19.0	19.0	31.2	19.4
Average miles per day per party	0.86	1.02	0.95	0.89	0.65
Total cost subsistence	$515.55	$273.07	$59.50	$599.20	$574.45
Average daily cost subsistence	$0.37	$0.39	$0.39	$0.40	$0.59
Total payroll (except teams)	$2,410.10	$1,143.11	$242.70	$2,562.74	$2,049.25
Average daily pay per man	$1.72	$1.61	$1.61	$1.71	$1.60
Total cost for teams	$434.74	$212.71	$43.10	$496.00	$445.85
Daily cost for teams	$6.69	$5.75	$5.39	$10.33	$6.76
Contingencies	$143.36	$46.76	$15.70	$196.00	$133.84
Total cost of party	$3,503.75	$1,675.65	$361.00	$3,893.94	$3,203.59
Daily cost of party	$53.90	$45.22	$45.12	$80.29	$48.54
Daily cost per man	$2.50	$2.36	$2.39	$2.57	$2.50
Cost per mile	$62.57	$44.33	$47.50	$90.47	$81.72
Relative percentage to lowest man per mile	141	100	107	204	184

embraced the heaviest work on the whole line; at the same time, much difficulty was experienced in getting a grade between certain points on the line located by Party No. 3. Party No. 2 had the lightest country.

There is charged to the expense of Party No. 4, the cost of moving a long distance from other work to this line, which amount, together with the short time they were engaged on preliminary, abnormally increased the cost of their work; at the same time, it is evident that this was decidedly the most expensive party on the work, their work, per unit of cost, costing more.

For instance, their subsistence was 57% more than that of Party No. 1, and the team hire more than double that of the other parties; while the actual number of men in the field was relatively the same. It is probable that the cost of the work done by this party was really about 60% more than the others, instead of 200%, as shown by the cost per mile.

On location, Party No. 1 carried a very heavy and expensive sounding party, consisting of a man in charge, four or five labor-

ers and a team; the nature of this work was such that it was much more expensive than that conducted by any of the other parties.

After completing the location, Party No. 1 was engaged in running other preliminaries and locating a short branch, the cost of this work not being distributed, but included in the total cost of the survey, the amount being $2,478.02.

On location, Parties Nos. 2 and 3 were combined after each had run in a short distance separately; this was necessitated by the approaching cold weather and the desire to complete the location at the earliest possible moment; the result shows it to have been an uneconomical proposition as far as cost per mile is concerned; but both of these parties had much additional preliminary work to perform as they proceeded with the location.

What has been noted of Party No. 4 on preliminary is true on location, though its cost is somewhat burdened by the charges incident to moving the party elsewhere, and the fact of its happening about Christmas, when many men were given vacations with pay. This Christmas expense was encountered to a somewhat less extent by every one of the parties, and tended to increase the total cost, but, taken as to Parties Nos. 1, 2 and 3, the statement is a fair average of what a thorough survey under like conditions will cost.

Besides the organization, as noted in Chap. III., which was practically the same as that engaged on these surveys, there was the expense of an expert, at $150 per month and his expenses, engaged in an examination of the country adjacent to the line, for the purpose of determining the quantity of sand and stone available for construction purposes. The amount of this expense was $545.84.

CHAPTER IX.

SURVEYS IN TROPICAL COUNTRIES AND NOTES ON MODIFICATIONS OF ORGANIZATION AND EQUIPMENT.

The tropical countries most likely to engage the attention of American engineers in the immediate future are those of Central and South America and the Philippines. In the whole of this vast territory, with the exception of Brazil, where Portuguese is spoken, and a few small islands in the West Indies, Spanish is the universal language south of the United States, and some knowledge of it is therefore eminently desirable, though not absolutely necessary to the engineer who is engaged in work in these countries.

Railroad systems in the Argentine, Chile and Mexico have reached considerable proportions, and the facilities for transportation in these countries may be said to be fairly well developed. The rest of South and Central America, with the possible exception of Peru (where the famous Oroya R. R. is located), is almost entirely undeveloped and presents a vast field for the enterprise of American railroad managers and engineers, whose methods of railroad construction are generally better adapted to the exploitation of undeveloped countries than those of European engineers.

Owing to the expense of transportation, both on the ground, and to and from the United States, parties organized for work in the tropics are usually quite small, as few men as possible being taken down, and the party filled out with men obtained in the country.

For a preliminary survey and report no consideration should be given, in the writer's opinion, to anything but stadia methods, and for this only two men are absolutely necessary besides the chief of party. If for location to be followed by construction, the locating party need be limited as to size only by the number of men necessary to take care of the construction.

Salaries in the tropics should be from 50% to 100% more than

in the United States, and all expenses paid from New York, or other point of departure to the site of the work, and return expenses on completion of satisfactory service. Such men as rodmen and chainmen can be usually obtained in the country. The writer has used men from both the educated and peon classes and got good work out of both. The educated Spanish-American does not as a rule take to the hard work incidental to railroad location, but by exercising care in selection and training, men can be obtained to do the work satisfactorily.

In selecting an outfit for use in the tropics, care should be exercised that everything is of first-class quality, as the preservation of the health of the men is of the utmost importance. Tents, with a fly for each, of light weight duck should be selected, as everything will in all probability have to be packed on burros (donkeys). Everything must be arranged to be done up in packages weighing not over 50 lbs. each, two of which packages will make a load or pack for one burro, unless, as in the case of a tent, the article can be arranged as a pack in itself.

There are practically no roads worthy of the name in most of the tropical countries, all transportation having to be conducted by pack animals or boat.

In selecting the cooking utensils, the size of the party must be borne in mind, that is, the number of Americans; the natives will usually prefer to take care of their own subsistence, so the matter is much simplified, and the outfit in this regard may be cut down quite low; where weight is a consideration, aluminum cooking utensils may be used to advantage. Cots and mosquito bars should be provided for all the Americans; it seems hardly necessary at this late day to point out the fact that yellow fever and malaria may be absolutely prevented by keeping away the mosquitoes, and that malaria is not due to bad air, newly dug earth or miasmatic vapors, as had long been supposed, or that yellow fever is not contagious, and can only be communicated by the particular kind of mosquito that breeds in the vicinity of dwelling houses. Sleeping on the ground or in the open air is dangerous, on account of the dampness and very heavy dew. The best form of mosquito bar is that described on page 213.

Waterproof coverings should be provided for everything which may get injured by getting wet. Clothes and personal

effects to be actually used on the survey can be packed in a rubber bag, with a canvas bag outside. Such bags as sailors use, about 15 inches diameter and 36 inches long, tied at one end, are very convenient.

Trunks can, of course, be taken, and left at the town or city where the survey begins; but tarpaulin or other waterproof coverings should be provided if they have to be transported inland.

Americans engaged on work of this kind are often the recipients of considerable courtesy at the hands of both public officials and private individuals, and they should, if possible, be provided with a dress suit, which is always *de rigueur* on ceremonial occasions, even in the day time.

The principal articles of personal equipment to be taken from the U. S. are shoes, leggins, underwear, socks, negligee, or blue flannel shirts, and linen collars; everything else can in most cases be obtained cheaper and better in the country than in the U. S. Khaki suits are very serviceable, and they can now be obtained almost everywhere. It might be advisable to have one white linen suit and one khaki suit ready to use on landing, or as many more as one's purse allows.

A very moderate use of alcoholic liquor in the tropics is probably beneficial; but more than this is undoubtedly much more injurious than in a temperate climate. Owing to the lack of social life, as we understand it, and of any form of amusement, the saloon is apt to be the only place of recreation, and the temptation to over-indulgence in this regard much greater than would otherwise be the case, though it is bound to be fatal to a man's future, if not to his health, and extreme care must be exercised in selecting men for this class of work to see that they are not apt to fail in this regard.

Cold baths should be avoided, and, if caught in a tropical rainstorm, or after being forced to wade a river, care should be taken to get a vigorous rubbing with rough towels as soon as possible after, and get into dry clothes. Great care also should be taken to avoid cold drinks when heated.

In countries where cholera is prevalent, practical immunity may be attained, even when living in the midst of an epidemic, if care is taken to drink only water that has been boiled and then kept sterilized, and to eat hot, well-cooked food.

Saddle horses should be provided for the engineers in the party, and a man provided to carry the instruments. Peons get 30 or 40 cents a day in gold, and it costs $400 or $500 to get another man from the States, besides the delay in case of sickness. It is especially important that every man on the party be at least capable of filling the next higher position, and salaries should be graded accordingly.

If a man has become accustomed to any particular type of saddle, he had better take one with him, and have it fitted with good, generous saddle bags. The native saddles can be used; but the writer prefers a Whitman, and men who have ridden a great deal, generally have decided preferences.

No old, half-worn-out clothes should be taken, as there is little time or opportunity to repair them, and they are a nuisance. The writer took the following outfit for a trip which was expected to last six months:

1 pair patent leather shoes.	3 white linen suits.
2 pair light-weight russet shoes.	2 khaki suits.
2 pair heavy-weight russet shoes.	1 dozen negligee shirts.
1 pair heavy leather leggins.	2 dozen linen collars.
½ dozen pairs good socks.	1 Stetson hat.
2 dozen pairs cheap socks.	2 dozen large cotton handkerchiefs.
½ dozen undershirts, light weight.	3 kamarbands.
1 doz. pair drawers, light weight.	

The kamarband, a woolen or flannel band worn around the waist, is especially important in hot climates to prevent rapid changes of temperature of the stomach.

Besides this, of course, the ordinary outfit of clothes which one would take anywhere for a short visit. A heavy overcoat and heavy underwear should always be taken, as one is liable to come north in the winter. The possibility of the work being in mountainous regions must be considered, of course, and the party should not start off with the mistaken idea that because the location is in the tropics it is necessarily hot.

In Northern Mexico, in fact, on the whole central plateau as far south as Mexico City, at an elevation of from 5,000 ft. to 8,000 ft. above sea level, some quite cold days are experienced in winter, though ordinarily the climate is about the same as that on a bright, crisp autumn day in New England or New York, and a light weight overcoat is comfortable. In summer the days are rarely unpleasantly warm, and the nights are always cool. Bogotá,

in Colombia, and Quito, in Ecuador, both very near the equator, are very much the same, as is also the central Bolivian plateau and the elevated plateau reached by the Uganda Ry. in East Africa.

It will be well to provide two or three extra flys for the laborers and servants to sleep under and to shelter the horses.

With a small party of, say, four men, one tent with a fly over it and one fly extended beyond the tent and on line with it will be enough; one tent fly for the cook, and a couple more for the men and horses. Two tables may be carried similar to those shown (Fig. 10); but one should have shorter legs, to be used as a dining table, and the tops can be hinged and the trestles so arranged that they can be taken apart and made into convenient packs.

Engineers should be careful to assure themselves of the financial responsibility of the promoters of any of these enterprises. There have been and will be many wild-cat schemes started in these countries, and men left stranded there, and it's a bad place for an engineer to be out of a job and with no money.

The educated classes of South and Central America number among them men who compare favorably with men in similar positions anywhere. They are frequently found to have been educated in New York, London, Paris, or Berlin, and to a much larger extent in proportion to their numbers have that liberal-minded tolerance for other nations than their own, which bespeaks the cultivated traveller. They have perhaps a somewhat exaggerated regard for the outward courtesies of social intercourse, though it is doubtful if their protestations of politeness are as hollow as many of those of our own so-called polite society, and the American engineer will do well to cultivate their regard by attention to these himself. Servility is not necessary, nor any approach to it, but a scrupulous regard for politeness in one's intercourse with the people of the country will go a long way, and enable the man who practices it to go much farther and get far more, than the man who thinks he is showing his independence and Anglo-Saxon superiority by being a boor.

Absolute honesty and a scrupulous regard for one's word, and to see that all promises made, whether of punishment or reward or in fulfilment of contracts, verbal or otherwise, are carried out in the full spirit of their intention, is absolutely necessary, espe-

cially as the engineer's particular knowledge of his profession gives him an advantage over those with whom he has dealings much greater than he might have at home, where he is dealing with those who better understand him and his work.

Reliable maps are almost an unknown quantity, and as large areas are densely wooded and covered with almost impenetrable underbrush, the preliminary reconnaissance is a matter of considerable difficulty. The writer would recommend running rapid stadia lines over all the trails in the vicinity of the proposed route as a basis for a preliminary map, and to obtain accurate information on which to base the preliminary campaign. On account of the dense underbrush, through which often a man cannot walk at all, and where the vision is limited to a very few yards, it is impractical to run lines and take topography as in more open country; still, a good topographer with three or four macheteros (axemen) can get much valuable information.

The line must be put nearly where it belongs by main strength, and after the clearing is done, minor changes of alignment can be made, as land is generally not very valuable, and enough right of way can be obtained so that this may be done.

For supplies on such a trip, if not too long, the country should be relied on. Ham and bacon, however, the mainstay of the American pioneer, cannot be obtained, and it will be well to take a supply. If the stay is to be prolonged, other supplies as may appear necessary after an investigation of the resources of the country can be ordered and shipped. Arrangements for this should be made with some reliable dealer before starting.

Nearly all of these countries require the metric system to be used for all surveys and records; and tapes, rods, etc., should be graduated accordingly, though the angular subdivisions of minutes and seconds remain the same. A little experience will show how much all computations are simplified by this system.

Stakes are usually set every 20 meters (about 66 ft.), and numbered from zero, 2, 4, 6, 8, etc. Twenty meters is usually spoken of as one station, although 10 meters (1 dekameter) is the basis of the numbering, the plus of a point, say 14.68 meters beyond Sta. 8 being written 9 + 4.68.

Metric curves are based on a chord of 20 meters, the angle subtended at the centre of the circle by this chord being the index

of the curve. Thus in a 4° metric curve an angle of 4° at the centre will subtend a chord of 20 meters (66 ft. approx.) at the circumference. The radius, therefore, will be about two-thirds that corresponding to the American system, where the same angle will subtend a chord of 100 ft. For mental comparison, therefore, it may be remembered that a 4° metric curve = approximately, a 6° curve of the American system, or $1\frac{1}{2}$ times as much, and the same proportion, of course, for any degree.

Metric curves are calculated and run in, in exactly the same manner as ordinary curves, substituting, of course, the radii as given in Table XIII., and in calculating odd stations remembering that the whole deflection is for 20 meters. Thus the deflection for 17.28 meters of 6° curve metric would be:

$$\frac{17.28}{20} \text{ of } 3^\circ = 2^\circ\ 35'\ 31''.$$

In calculating earthwork where the ground is such that sections need only be taken at each stake, i. e., every 20 meters, the operation is very simple. Suppose at Sta. 24 the area of the cross section is found to be 8.43 sq. meters, and at Sta. 26, 10.72 sq. meters, it is obvious that the cubic contents are 191.5 cubic meters, obtained by adding the two end areas and pointing off one place, in detail:

$$\frac{10.72 + 8.43}{2} \times 20 = 191.5.$$

The type of road to be built in any of these countries depends as always and elsewhere on local conditions. On a road in Northern Mexico with which the writer was connected it was found that the difference in cost between timber, and steel bridges with masonry abutments, was so small, owing to the high price of timber and low price of masonry (laid in lime mortar of excellent quality), that all structures were of permanent construction from the beginning. In the tropics ordinary timber will not last in the ground at all, being eaten by the white ants (comajeng), and such hard woods as lignum vitae, etc., have to be used for ties; woods so hard, that holes have to be bored for the spikes before they can be driven, and wooden bridges built of very heavily creosoted lumber.

In determining the width of roadbed, due consideration must be given to the excessive downpours of rain which occur at times in the tropics, and as a rule cuts should be made not less than 2 ft. wider than is usual in temperate climates, to allow for proper drainage ditches; and in estimating costs, due consideration must be given to the fact that everything used both for and in the construction and operation must be brought from the United States, and freight and possible customs duties added.

In Mexico it is necessary to file a map of the location before construction can be started. These maps are required to be drawn on sheets about 1.20 m. × 0.60 m., and at a scale of 1:10,000 for the map, and for the profile 1:10,000 horizontal and 1:1,000 vertical; each sheet must show a section of 10 kilometers. The map to show besides the alignment notes, topography for 300 meters on either side of the line, most of which may be sketched; but roads and streams must be located, the profile must show the grade line and rate of grade, and a table must be drawn up, giving the elevation of ground and grade line at each station, and the cut or fill. Sections of roadbed in both cuts and fills must be shown on each sheet. The regulations governing these maps specify the requirements in considerable detail, and a copy should be procured from the government official. An inspector is appointed by the government at the expense of the R. R. Co., who must pass on the location and plans for construction.

It is often necessary, not only in the tropics but in the United States, for one reason or another, to make a survey with a limited number of men, especially in case of a very short road. Where, say, 20 or 30 miles have to be located, it would obviously be out of the question to organize a large party for only a couple of weeks' work. The reconnaissance would, of course, be made of the whole area before the party was put in the field, two or three days being usually sufficient for this, and the party can then be organized as follows, besides the locating engineer:

Transitman,
Leveller,
Rodman,
Back flag,
Stakeman,
Axemen as necessary.

When the line is being run, the whole party can be used as a transit party, the leveller acting as head chain and the rodman as rear chain. Whilst levels are being run by the leveller and rodman, the transitman can be getting topography with the rest of the party, whilst the chief of party is platting the map or making further reconnaissance.

The writer has made more than one survey in this manner, and there will be many instances where as full an organization as that noted in Chapter III. cannot be obtained; but the intelligent engineer will easily find means to work all the men to advantage, and finally get the results at the expense of a little more time. It should not be thought that the organization referred to (Chapter III.) is necessary to get the work done as advocated; simply that where the work warrants it, as it does on a long line, such an organization is the most economical in the long run.

In much mountain country and in all unsettled countries vehicles are out of the question, and pack animals have to be used, or in extreme cases, men, to transport supplies; in which cases due consideration must be given to the equipment that it may be conveniently subdivided into sufficiently small packages to meet these conditions. Abut 300 lbs. is considered a fair load for a pack animal to be carried all day, and 75 to 90 lbs. for a man, although it is stated (Engineering News, Dec. 14, 1905) that loads of 200 lbs. were carried across portages by Canadian Indians in connection with the surveys for the Grand Trunk R. R. In these cases, personal equipment as well as everything else must be cut down to the lowest possible point.

In cold climates where warm bedding is necessary and transportation facilities limited, sleeping bags, wool or fur-lined, give probably the largest amount of comfort for the smallest weight. Cots can be cut out if necessary, and especially in the northern woods, where the small pine and fir branches make a fine bed.

Mosquito netting should always be provided where necessary, either for mosquitoes or flies, and should be, though it seldom is, at the expense of the company. Where flies or mosquitoes are bad in the day time, the following is recommended by Mr. O. H. Tripp*: "For a man using an instrument (or for similar work), the best protection for the hands and wrists is a pair of light-

*Trans. Am. Soc. C. E., Vol. LIV., p. 165.

weight oil-tanned gloves, with the tips of the fingers cut off and a piece of thin leather sewed into the opening in the palm. The leg of a thin stocking (or enough of it to reach at least to the elbow) should be sewed to the wrist of the glove. This will be serviceable in stopping vermin of all kinds. For oil there is nothing better than castor oil, with oil of pennyroyal (2 or 3 oz. of the latter to 1 pint of the former), and with enough oil of tar to give the mixture a good, clear mahogany color. On going out in the morning, this should be applied to the face and neck freely and frequently, until a coating is formed on the skin; after that an application every half hour through the day usually answers the purpose."

The writer personally has had more trouble with the "jigger," or chigoe, than any other insect pest. These are mostly confined to warm climates, but are found everywhere, from Kansas to the Equator, that he has visited, which includes nearly the whole range between these points. They generally attack the leg between the ankle and knee, and no kind of material protection seems to be able to keep them out. Some remedy to be applied to the skin is absolutely necessary, and can usually be obtained in the country where they are found. Amongst other things, the writer has used a saturated solution of camphor in alcohol, or a solution of sulhpur in carbon disulphide. This latter is very efficacious, if one can stand the odor.

In a survey in the Florida Everglades,* where no animals of any kind could be used, each man carried his whole outfit on his back, and supplies had to be packed on men's backs from a base. The climate, of course, was warm, with frequent rains. No tents were used, but a couple of flies were carried to protect the goods, and as a shelter in heavy rains. Cooking utensils were of aluminum, and a complete outfit for eight men nested in one pot, and weighed barely 15 lbs. entire. Each member of the field party was furnished with a stout canvas knapsack, and the limit of the personal outfit was what each man could carry on his back.

"Various materials were tried for field clothing, with more or less success. Pantasote sheeting was found too warm for the climate and gave poor service. Canvas wore well and dried quickly

*Engineering Record, April 2 and 9, 1904.

after being wet, but is too stiff and uncomfortable to make a desirable working garment. A good grade of khaki, well made, was found to give the best satisfaction of any fabric tried, and has been used with success on subsequent work. It wears well, dries quickly, and is soft and easy fitting. Foot-gear caused much trouble. Rubber is a poor material for the purpose under any conditions, and in a warm climate, for regular wear, will not do at all. The best of leather when soaked in water for hours and then pounded over coral reefs indescribably rough and sharp, soon shows signs of grief. Ordinary shoes do well to last a single week. A half-boot, lacing to the top through large eyelets (hooks are a nuisance), Blucher cut with bellows tongue, a heavy sole and stiff counter came nearer meeting the requirements than any other type. The soles were kept thickly studded with hob-nails and the uppers were pierced, well down, to let the water out. To keep it out when wading waist deep was an impossibility.

"The mosquito plague being one of the most serious obstacles that was encountered, each man was provided with a bar, and the proper stretching of these became quite an art. About the best bar for this purpose is made of cheesecloth with a canvas roof. The canvas top should be 7 feet long by 3 feet wide, with loops or grommets at the corners. The cheesecloth should have a depth of about 5 feet, and be sewed to the under side of the roof, leaving 2 inches of the canvas projecting all around. If this projection is stiffened with buckram or by doubling, and the roof of the bar stretched flat when pitched, it will shed a light rain quite well and the water will not run down the sides. These nets may be stretched from a stake at each corner, or by putting in a spreader across the ends, two stakes will answer.

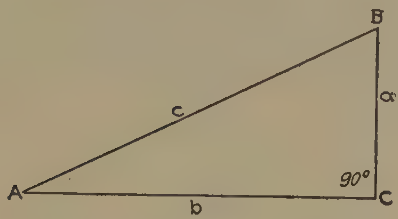
"Head nets are uncomfortable affairs at best, but their use on this work was at times imperative. Cheesecloth and bobbinet are too hot and are very hard to see through. The net that was most satisfactory was that worn by the Cape Sable squatters. It is built for use over a stiff rimmed hat, and consists of a band of 10-ounce canvas, fitting closely around the crown of the hat and extending out to the edge of the rim. To this is firmly sewed a strip of close mesh copper wire netting extending down about 3 inches in the back and curving over the shoulders to the level of the wearer's chin. Cheesecloth is taped on around the bottom

of the copper gauze of sufficient width to tuck well inside the coat, which is buttoned over it. The wire netting is kept out from the face by the stiff brim of the hat, allows the air to pass through freely, and can be seen through with ease, it being possible to run an instrument quite well from inside one of these gilded cages. When not in use it can be completely removed from the hat, and there are no strings to become knotted or broken loose. It is, however, somewhat troublesome to carry."

TRIGONOMETRICAL AND CURVE FORMULAE, TABLES, ETC.

TRIGONOMETRICAL FORMULAE.

Solution of Right-angle Triangles.



Let A be any acute angle, and let B C be perpendicular to A C, then denoting the sides by the small letters and the angles by capitals as in the figure, we have

$$\text{Sin } A = \frac{a}{c} \qquad \text{Tan } A = \frac{a}{b}$$

$$\text{Cos } A = \frac{b}{c} \qquad \text{Cot } A = \frac{b}{a}$$

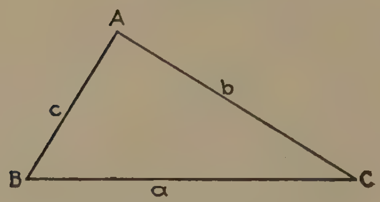
Given.	Sought.			
a c	A B b	$\text{Sin } A = \frac{a}{c}$	$\text{Cos } B = \frac{a}{c}$	$b = \sqrt{(c+a)(c-a)}$
a b	A B c	$\text{Tan } A = \frac{a}{b}$	$\text{Cot } B = \frac{a}{b}$	$c = \sqrt{a^2 + b^2}$
A a	B b c	$B = 90° - A$	$b = a \text{ Cot } A$	$c = \frac{a}{\text{Sin } A}$
A b	B a c	$B = 90° - A$	$a = b \text{ Tan } A$	$c = \frac{b}{\text{Cos } A}$
A c	B a b	$B = 90° - A$	$a = c \text{ Sin } A$	$b = c \text{ Cos } A.$

Solution of Any Plane Triangle.

Case 1.—Given 2 angles and one side.

Sine of the angle opposite the given side is to the sine of the angle opposite the required side as the given side is to the required side.

Example.



Given B C a

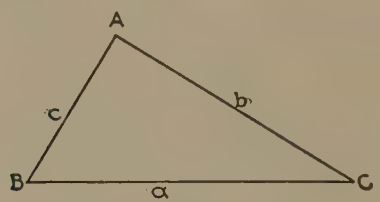
$$A = 180 - (B + C)$$

Then Sin A : Sin B : : a : b.

Case 2.—Given 2 sides and the angle opposite one of them.

Side opposite the given angle is to the side opposite required angle as the sine of the given angle is to the sine of the required angle.

Example.



Given a b B

b : a : : Sin B : Sin A.

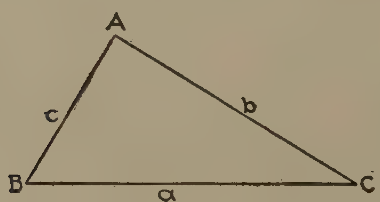
Then find c by Case 1.

Case 3.—Given 2 sides and included angle.

Sum of the sides is to their difference as the Tan of half the sum of the two unknown angles is to the Tan of half their difference.

Add half the sum to half the difference for one angle. Subtract half the difference from half the sum for the other.

Example.



Given a c B

$$A + C = 180^\circ - B.$$

$$(a + c) : (a - c) : : \text{Tan}\left(\frac{A+C}{2}\right) : \text{Tan}\left(\frac{A-C}{2}\right)$$

$$\text{Add } \frac{A+C}{2} \text{ to } \frac{A-C}{2} \text{ for A.}$$

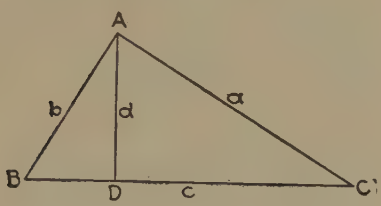
$$\text{Subtract } \frac{A-C}{2} \text{ from } \frac{A+C}{2} \text{ for C.}$$

Case 4.—Given 3 sides.

Suppose a perpendicular be dropped from one angle to the opposite side, which latter is called the base. The base is to sum of other two sides, as the difference of the other two sides is to the difference of the two parts of the base on either side of the perpendicular.

Add half the difference of the two parts (as found) to half the base, and the sum will be the longest part. Then solve two right angle triangles.

Example.



Given a b c,

Make A D perpendicular to B C.

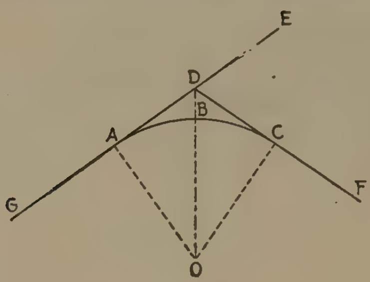
Then $c : (a + b) :: (a - b) : (DC - BD)$.

Then add $\dfrac{DC - BD}{2}$ to $\dfrac{BC}{2}$ to get D C.

$$BD = BC - DC.$$

Then solve the two right-angle triangles.

CURVE NOMENCLATURE, FORMULAE, ETC.



In the above figure,

Let A B C be any curve.

O A, O B, O C, Radii.

Angles D A O and D C O being right angles, D G and D F are tangent to the curve at the points A and C respectively.

A D and D C are known variously as Semi-Tangents, Sub-Tangents or Tangent Distances, and are designated by S T or T.

Angle E D F is the intersection angle, is equal to A O C, the Central Angle, and is designated I.

D B is the External Distance, or External or External Secant, and is designated Ext. or E.

The degree of curve is the index number corresponding to the number of degrees of central angle subtended by a cord of one hundred feet, as, for example, when we say 3° curve, a curve is indicated on which a chord of 100 ft. subtends an angle of 3° at the centre. In using the metric system a chord of 20 meters is used in the same relation.

P C = Point of Curve or Beginning of Curve.
P T = Point of Tangent or End of Curve.
P C C = Point of Compound Curve or end of one curve and beginning of another of different index number in the same direction.
P R C = Point of Reverse Curve (this should be rarely, if ever, necessary).
P I = Point of Intersection (of Tangents). (D in above figure.)
I = Intersection Angle. (E. D. F.)

Curve Formulae.

T = Semi Tangent = Tangent Distance.
R = Radius.
D = Degree of Curve, = Δ Delta.
I = Intersection angle = Central Angle.
L = L C = Length of Curve.
E = External = External Distance.

American system, using 100-ft. chords.

$$R = \frac{50}{\text{Sin } \frac{1}{2} D} \qquad T = R \text{ Tan } \tfrac{1}{2} I$$

$$I = \frac{D L}{100} \qquad D = 100 \frac{I}{L}$$

$$L = 100 \frac{I}{D} \qquad R = T \text{ Cot } \tfrac{1}{2} I$$

Metric system, using 20-meter chords.

$$R = \frac{10}{\text{Sin } \frac{1}{2} D} \qquad T = R \text{ Tan } \tfrac{1}{2} I$$

$$I = \frac{D L}{20} \qquad D = 20 \frac{I}{L}$$

$$L = 20 \frac{I}{D} \qquad R = T \text{ Cot } \tfrac{1}{2} I$$

TABLES OF LEVEL CUTTINGS FOR 100-FOOT STATIONS.

These tables of level cuttings are given for ordinary widths of single and double track roadbed. Tables for any other widths of roadbed can easily be calculated. Quantity scales made up as shown (Fig. 32) will be found to save much time, and should be made up by the draftsman at the beginning of the survey for the width of roadbed to be used and the various slopes.

TABLE XI.

Cubic Yards per Station of 100 ft.

Single Track Roadbed. Embankments, 16 ft. Cuttings, 18 ft.

Height.	Roadbed, 16 ft. 1½ to 1.	Roadbed 18 ft. 1 to 1	Roadbed 18 ft. ½ to 1	Roadbed 18 ft. ¼ to 1.
1	65	70	69	68
2	141	148	141	137
3	228	233	217	208
4	326	325	296	282
5	435	426	380	357
6	556	533	467	433
7	687	648	557	512
8	830	770	652	593
9	983	900	750	675
10	1,148	1,037	852	759
11	1,324	1,181	957	845
12	1,511	1,333	1,067	933
13	1,709	1,493	1,180	1,023
14	1,919	1,659	1,296	1 115
15	2,139	1,833	1,417	1,208
16	2,370	2,015	1,541	1,304
17	2,613	2,204	1,668	1 401
18	2,867	2,400	1,800	1,500
19	3,131	2,604	1,935	1,601
20	3,407	2,815	2,074	1,703
21	3,694	3 033	2,217	1,808
22	3,994	3 259	2,363	1,916
23	4 302	3 493	2,513	2,024
24	4,622	3,733	2,667	2,133
25	4,954	3,981	2,825	2 245
26	5,296	4,237	2,985	2,359
27	5,650	4,500	3,150	2,475
28	6,015	4,770	3,318	2 592
29	6,391	5,048	3,491	2 712
30	6,778	5,333	3,667	2,833
31	7,176	5,626	3,846	2,956
32	7,585	5,926	4,030	3 081
33	8,006	6,233	4 217	3,208
34	8,437	6,548	4 407	3 337
35	8,880	6,870	4 602	3 467
36	9,333	7,200	4 800	3 600
37	9 798	7,537	5,002	3 734
38	10,274	7,881	5,207	3 870
39	10,761	8 233	5,417	4,008
40	11,259	8,593	5,630	4,148
41	11,769	8,959	5,846	4,290
42	12 289	9,333	6,067	4,433
43	12,820	9,715	6,291	4,579
44	13,363	10,104	6 519	4,726
45	13,917	10,500	6,750	4,875
46	14 481	10,904	6,985	5,026
47	15,057	11,315	7,224	5,179
48	15 644	11,733	7,467	5 333
49	16,243	12,159	7,713	5,490
50	16,852	12,593	7,963	5,648

TABLE XII.

Double Track Roadbed. Embankments 28 ft. Cuttings 30 ft.

Height.	Roadbed 28 ft. Slopes 1½ to 1.	Roadbed 30 ft. 1 to 1.	Roadbed 30 ft. ½ to 1.	Roadbed 30 ft. ¼ to 1.
1	109	113	112	112
2	230	237	229	225
3	361	367	350	342
4	504	504	474	459
5	657	648	602	579
6	822	800	733	700
7	998	959	869	823
8	1,185	1,126	1,007	948
9	1,383	1,300	1,150	1,075
10	1,593	1,481	1,296	1,204
11	1,813	1,679	1,446	1,334
12	2,044	1,867	1,600	1,467
13	2,287	2,070	1,757	1,601
14	2,541	2,281	1,919	1,737
15	2,806	2,500	2,083	1,875
16	3,081	2,726	2,252	2,015
17	3,369	2,959	2,424	2,156
18	3,667	3,200	2,600	2,300
19	3,976	3,448	2,779	2,445
20	4,296	3,704	2,963	2,593
21	4,628	3,967	3,150	2,742
22	4,970	4,237	3,341	2,893
23	5,324	4,515	3,535	3,045
24	5,689	4,800	3,734	3,200
25	6,065	5,093	3,935	3,356
26	6,452	5,393	4,140	3,515
27	6,850	5,700	4,350	3,675
28	7,259	6,015	4,563	3,837
29	7,680	6,337	4,760	4,001
30	8,111	6,667	5,000	4,187
31	8,554	7,004	5,223	4,334
32	9,007	7,348	5,452	4,504
33	9,472	7,700	5,683	4,675
34	9,948	8,059	5,919	4,848
35	10,435	8,426	6,167	5,023
36	10,933	8,800	6,400	5,200
37	11,443	9,181	6,640	5,379
38	11,963	9,570	6,896	5,559
39	12,494	9,967	7,150	5,742
40	13,037	10,370	7,407	5,926
41	13,591	10,781	7,669	6,112
42	14,156	11,200	7,933	6,300
43	14,731	11,626	8,201	6,490
44	15,319	12,053	8,474	6,681
45	15,917	12,500	8,750	6,876
46	16,526	12,948	9,030	7,070
47	17,146	13,404	9,313	7,268
48	17,778	13,867	9,600	7,467
49	18,420	14,337	9,891	7,667
50	19,074	14,815	10,185	7,870

TABLE XIII.—Radii of Metric Curves.*

Degree per 20m Chord. D.	Radius of curve. R.	D.	R.	D.	R.	D.	R.
		40	687.57	20	343.82	5° 0′	229.26
		42	674.09	22	340.42	2	227.74
		44	661.13	24	337.08	4	226.24
		46	648.66	26	333.81	6	224.76
		48	636.65	28	330.60	8	223.30
0° 10	6875.5	50	625.07	30	327.46	10	221.87
12	5729.6	52	613.91	32	324.37	12	220.44
14	4911.1	54	603.14	34	321.34	14	219.04
16	4297.2	56	592.74	36	318.36	16	217.66
18	3819.7	58	582.70	38	315.44	18	216.29
20	3437.8	2° 0′	572.99	40	312.58	20	214.94
22	3125.2	2	563.59	42	309.76	22	213.60
24	2864.8	4	554.51	44	307.00	24	212.29
26	2644.4	6	545.70	46	304.28	26	210.98
28	2455.5	8	537.18	48	301.61	28	209.70
30	2291.8	10	528.92	50	298.99	30	208.43
32	2148.6	12	520.90	52	296.41	32	207.17
34	2022.2	14	513.13	54	293.88	34	205.93
36	1909.9	16	505.58	56	291.39	36	204.71
38	1809.3	18	498.26	58	288.94	38	203.50
40	1718.9	20	491.14	4° 0′	286.54	40	202.30
42	1637.0	22	484.22	2	284.17	42	201.12
44	1562.6	24	477.50	4	281.84	44	199.95
46	1494.7	26	470.96	6	279.55	46	198.80
48	1432.4	28	464.60	8	277.30	48	197.66
50	1375.1	30	458.40	10	275.08	50	196.53
52	1322.2	32	452.37	12	272.90	52	195.41
54	1273.3	34	446.50	14	270.75	54	194.31
56	1227.8	36	440.78	16	268.64	56	193.22
58	1185.4	38	435.20	18	266.55	58	192.14
1° 0′	1145.9	40	429.76	20	264.51	6° 0′	191.07
2	1109.0	42	424.45	22	262.49	2	190.02
4	1074.3	44	419.28	24	260.50	4	188.98
6	1041.8	46	414.23	26	258.54	6	187.94
8	1011.1	48	409.30	28	256.61	8	186.92
10	982.23	50	404.48	30	254.71	10	185.91
12	954.95	52	399.78	32	252.84	12	184.92
14	929.14	54	395.19	34	251.00	14	183.93
16	904.69	56	390.70	36	249.18	16	182.95
18	881.49	58	386.31	38	247.39	18	181.98
20	859.46	3° 0	382.02	40	245.62	20	181.03
22	838.49	2	377.82	42	243.88	22	180.08
24	818.53	4	373.71	44	242.16	24	179.14
26	799.50	6	369.70	46	240.47	26	178.22
28	781.33	8	365.76	48	238.80	28	177.30
30	763.97	10	361.91	50	237.16	30	176.39
32	747.36	12	358.15	52	235.53	32	175.49
34	731.46	14	354.45	54	233.93	34	174.60
36	716.22	16	350.84	56	232.35	36	173.72
38	701.60	18	347.30	58	230.79	38	172.85

* From Tables for Transitmen, by H. H. Filley, M. Am. Soc C. E., Kansas City, Mo.

TABLE XIII.—Radii of Metric Curves.—Continued.

D.	R.	D.	R.	D.	R.	D.	R.
40	171.98	20	137.63	10° 0'	114.74	40	98.26
42	171.13	22	137.08	2	114.36	42	97.98
44	170.28	24	136.54	4	113.98	44	97.71
46	169.45	26	136.00	6	113.60	46	97.43
48	168.62	28	135.47	8	113.23	48	97.15
50	167.79	30	134.94	10	112.86	50	96.88
52	166.98	32	134.41	12	112.49	52	96.61
54	166.18	34	133.89	14	112.13	54	96.34
56	165.38	36	133.37	16	111.76	56	96.07
58	164.59	38	132.86	18	111.40	58	95.80
7° 0'	163.80	40	132.35	20	111.05	12° 0'	95.54
2	163.03	42	131.84	22	110.69	2	95.27
4	162.26	44	131.34	24	110.34	4	95.01
6	161.50	46	130.84	26	109.98	6	94.75
8	160.75	48	130.35	28	109.63	8	94.49
10	160.00	50	129.85	30	109.29	10	94.23
12	159.26	52	129.37	32	108.94	12	93.97
14	158.53	54	128.88	34	108.60	14	93.72
16	157.80	56	128.40	36	108.26	16	93.46
18	157.08	58	127.93	38	107.92	18	93.21
20	156.37	9° 0'	127.45	40	107.58	20	92.96
22	155.66	2	126.99	42	107.25	22	92.71
24	154.96	4	126.52	44	106.92	24	92.46
26	154.27	6	126.06	46	106.59	26	92.21
28	153.58	8	125.60	48	106.26	28	91.96
30	152.90	10	125.14	50	105.93	30	91.72
32	152.22	12	124.69	52	105.61	32	91.47
34	151.55	14	124.24	54	105.29	34	91.23
36	150.89	16	123.79	56	104.97	36	90.99
38	150.23	18	123.35	58	104.65	38	90.75
40	149.58	20	122.91	11° 0'	104.33	40	90.51
42	148.93	22	122.48	2	104.02	42	90.28
44	148.29	24	122.04	4	103.71	44	90.04
46	147.66	26	121.61	6	103.40	46	89.80
48	147.03	28	121.19	8	103.09	48	89.57
50	146.40	30	120.76	10	102.78	50	89.34
52	145.78	32	120.34	12	102.48	52	89.11
54	145.17	34	119.92	14	102.17	54	88.88
56	144.56	36	119.51	16	101.87	56	88.65
58	143.95	38	119.09	18	101.57	58	88.42
8° 0'	143.36	40	118.68	20	101.28	13° 0'	88.19
2	142.76	42	118.28	22	100.98	2	87.97
4	142.17	44	117.87	24	100.68	4	87.75
6	141.59	46	117.47	26	100.39	6	87.52
8	141.01	48	117.07	28	100.10	8	87.30
10	140.44	50	116.68	* 30	99.69	10	87.08
12	139.87	52	116.28	32	99.40	12	86.86
14	139.30	54	115.89	34	99.11	14	86.64
16	138.74	56	115.51	36	98.83	16	86.42
18	138.18	58	115.12	38	98.55	18	86.21

* Curves of less than 100m. radius should be located by 10m. chords.

TABLE XIV.—Tangents and Externals to a 1° Metric Curve.*

Angle.	Tang.	Exter.	Angle.	Tang.	Exter.	Angle.	Tang.	Exter.
1°	10.00	.044	9°	90.19	3.54	17°	171.3	12.73
10′	11.67	.059	10′	91.86	3.68	10′	173.0	12.98
20	13.33	.078	20	93.54	3.81	20	174.7	13.24
30	15.00	.098	30	95.22	3.95	30	176.4	13.49
40	16.67	.121	40	96.90	4.09	40	178.1	13.75
50	18.34	.147	50	98.58	4.23	50	179.8	14.02
2	20.00	.175	10	100.3	4.38	18	181.5	14.28
10	21.67	.205	10	101.9	4.52	10	183.2	14.55
20	23.34	.238	20	103.6	4.67	20	184.9	14.82
30	25.00	.273	30	105.3	4.83	30	186.6	15.10
40	26.67	.310	40	107.0	4.98	40	188.3	15.37
50	28.34	.350	50	108.7	5.14	50	190.0	15.65
3	30.01	.393	11°	110.3	5.30	19	191.8	15.93
10	31.68	.438	10	112.0	5.46	10	193.5	16.22
20	33.34	.485	20	113.7	5.63	20	195.2	16.50
30	35.01	.535	30	115.4	5.79	30	196.9	16.79
40	36.68	.587	40	117.1	5.96	40	198.6	17.09
50	38.35	.641	50	118.8	6.14	50	200.3	17.38
4	40.02	.698	12	120.4	6.31	20	202.1	17.68
10	41.69	.758	10	122.1	6.49	10	203.8	17.98
20	43.35	.820	20	123.8	6.67	20	205.5	18.28
30	45.02	.884	30	125.5	6.85	30	207.2	18.58
40	46.69	.951	40	127.2	7.04	40	208.9	18.89
50	48.36	1.02	50	128.9	7.22	50	210.7	19.20
5	50.03	1.09	13	130.6	7.41	21°	212.4	19.52
10	51.70	1.17	10	132.2	7.61	10	214.1	19.83
20	53.37	1.24	20	133.9	7.80	20	215.8	20.15
30	55.04	1.32	30	135.6	8.00	30	217.6	20.47
40	56.71	1.40	40	137.3	8.20	40	219.3	20.79
50	58.38	1.49	50	139.0	8.40	50	221.0	21.12
6	60.06	1.57	14	140.7	8.61	22	222.7	21.45
10	61.73	1.66	10	142.4	8.81	10	224.5	21.78
20	63.40	1.75	20	144.1	9.02	20	226.2	22.11
30	65.07	1.85	30	145.8	9.23	30	227.9	22.45
40	66.74	1.94	40	147.5	9.45	40	229.7	22.79
50	68.42	2.04	50	149.2	9.67	50	231.4	23.13
7	70.09	2.14	15	150.9	9.89	23	233.1	23.48
10	71.76	2.24	10	152.6	10.11	10	234.9	23.82
20	73.43	2.35	20	154.3	10.34	20	236.6	24.17
30	75.11	2.46	30	155.9	10.56	30	238.4	24.53
40	76.78	2.57	40	157.6	10.79	40	240.1	24.88
50	78.46	2.68	50	159.3	11.03	50	241.8	25.24
8	80.13	2.80	16	161.0	11.26	24	243.6	25.60
10	81.81	2.92	10	162.7	11.50	10	245.3	25.96
20	83.48	3.04	20	164.4	11.74	20	247.1	26.33
30	85.16	3.16	30	166.1	11.98	30	248.8	26.70
40	86.83	3.29	40	167.8	12.23	40	250.6	27.07
50	88.51	3.41	50	169.6	12.48	50	252.3	27.45

*From Tables for Transitmen, by H. H. Filley, M. Am. Soc. C. E., Kansas City, Mo.

TABLE XIV.—Tangents and Externals to a 1° Metric Curve.—Continued.

Angle.	Tang.	Exter.	Angle.	Tang.	Exter.	Angle.	Tang.	Exter.
25°	254.0	27.82	**33°**	339.4	49.22	**41°**	428.4	77.48
10′	255.8	28.20	10′	341.3	49.73	10′	430.3	78.14
20	257.5	28.59	20	343.1	50.25	20	432.2	78.80
30	259.3	28.97	30	344.9	50.77	30	434.2	79.49
40	261.1	29.36	40	346.7	51.30	40	436.1	80.16
50	262.8	29.75	50	348.5	51.83	50	438.0	80.84
26	264.6	30.14	**34**	350.3	52.36	**42**	439.9	81.53
10	266.3	30.54	10	352.2	52.89	10	441.8	82.21
20	268.1	30.94	20	354.0	53.43	20	443.7	82.90
30	269.8	31.34	30	355.8	53.97	30	445.6	83.60
40	271.6	31.74	40	357.6	54.52	40	447.5	84.30
50	273.4	32.15	50	359.5	55.06	50	449.5	85.00
27	275.1	32.56	**35**	361.3	55.61	**43**	451.4	85.70
10	276.9	32.97	10	363.1	56.16	10	453.3	86.41
20	278.6	33.39	20	365.0	56.72	20	455.2	87.12
30	280.4	33.81	30	366.8	57.28	30	457.2	87.83
40	282.2	34.23	40	368.7	57.84	40	459.1	88.55
50	283.9	34.65	50	370.5	58.40	50	461.0	89.27
28	285.7	35.08	**36**	372.3	58.97	**44**	463.0	90.00
10	287.5	35.51	10	374.2	59.54	10	464.9	90.72
20	289.3	35.94	20	376.0	60.12	20	466.9	91.45
30	291.0	36.38	30	377.9	60.69	30	468.8	92.19
40	292.8	36.82	40	379.7	61.27	40	470.8	92.93
50	294.6	37.26	50	381.6	61.86	50	472.7	93.67
29	296.4	37.70	**37**	383.4	62.44	**45**	474.7	94.42
10	298.1	38.15	10	385.3	63.03	10	476.6	95.16
20	299.9	38.60	20	387.1	63.63	20	478.6	95.92
30	301.7	39.05	30	389.0	64.22	30	480.5	96.67
40	303.5	39.51	40	390.9	64.82	40	482.5	97.43
50	305.3	39.96	50	392.7	65.42	50	484.5	98.20
30	307.1	40.42	**38**	394.6	66.03	**46**	486.4	98.96
10	308.8	40.89	10	396.4	66.64	10	488.4	99.73
20	310.6	41.35	20	398.3	67.25	20	490.4	100.5
30	312.4	41.82	30	400.2	67.86	30	492.3	101.3
40	314.2	42.30	40	402.0	68.48	40	494.3	102.1
50	316.0	42.77	50	403.9	69.10	50	496.3	102.8
31	317.8	43.25	**39**	405.8	69.73	**47**	498.3	103.6
10	319.6	43.73	10	407.7	70.36	10	500.2	104.4
20	321.4	44.22	20	409.6	70.99	20	502.2	105.2
30	323.2	44.70	30	411.4	71.62	30	504.2	106.0
40	325.0	45.19	40	413.3	72.26	40	506.2	106.8
50	326.8	45.68	50	415.2	72.90	50	508.2	107.6
32	328.6	46.18	**40**	417.1	73.54	**48**	510.2	108.4
10	330.4	46.68	10	419.0	74.19	10	512.2	109.3
20	332.2	47.18	20	420.9	74.84	20	514.2	110.1
30	334.0	47.69	30	422.8	75.49	30	516.2	110.9
40	335.8	48.19	40	424.7	76.15	40	518.2	111.7
50	337.6	48.70	50	426.5	76.81	50	520.2	112.5

TABLE XIV.—Tangents and Externals to a 1° Metric Curve.—Continued.

Angle.	Tang.	Exter.	Angle.	Tang.	Exter.	Angle.	Tang.	Exter.
49°	522 2	113.4	**57°**	622.2	158.0	**65°**	730.0	212.8
10′	524 2	114.2	10′	624.3	159.0	10′	732.4	214.0
20	526 3	115.1	20	626.5	16c.1	20	734.7	215.3
30	528.3	115.9	30	628 7	161.1	30	737.1	216 6
40	530 3	116.8	40	630.8	162.2	40	739.4	217.9
50	532.3	117.6	50	633.0	163.2	50	741.8	219.1
50	534.4	118.5	**58**	635.2	164.3	**66**	744.2	220.4
10	536.4	119.3	10	637 4	165.3	10	746.5	221.7
20	538.4	120.2	20	639 6	166.4	20	748.9	223.0
30	540.5	121.0	30	641.8	167.5	30	751.3	224.3
40	542.5	121 9	40	643.9	168.5	40	753.7	225.6
50	544.5	122.8	50	646.1	169.6	50	756.1	227.0
51	546 6	123.7	**59**	648.3	170.7	**67**	758.5	228.3
10	548.6	124.6	10	650.5	171.8	10	760 9	229.6
20	550.7	125 4	20	652.7	172 9	20	763.3	230.9
30	552.7	126.3	30	655.0	174 0	30	765.7	232.3
40	554.8	127.2	40	657.2	175 1	40	768 1	233.6
50	556.8	128.1	50	659.4	176.2	50	770.5	235.0
52	558.9	129.0	**60**	661.6	177.3	**68**	772.9	236.3
10	561.0	129.9	10	663.8	178 4	10	775 4	237.7
20	563.0	130.8	20	666.1	179.5	20	777.8	239.0
30	565 1	131.8	30	668.3	180.6	30	780.2	240.4
40	567.2	132.7	40	670.5	181.8	40	782.7	241.8
50	569.3	133.6	50	672.8	182.9	50	785.1	243.2
53	571.3	134.5	**61**	675.0	184.0	**69**	787.6	244.5
10	573.4	135.5	10	677.3	185.2	10	790.0	245.9
20	575.5	136.4	20	679.5	186.3	20	792.5	247.3
30	577.6	137.3	30	681.8	187.5	30	795 0	248.7
40	579.7	138.3	40	684.0	188.6	40	797.4	250.2
50	581.8	139.2	50	686.3	189.8	50	799 9	251.6
54	583.9	140.2	**62**	688.5	190.9	**70**	802.4	253.0
10	586.0	141.1	10	690.8	192 1	10	804.9	254.4
20	588.1	142.1	20	693.1	193.3	20	807.4	255.9
30	590.2	143.1	30	695 4	194.5	30	809.9	257 3
40	592.3	144.0	40	697.7	195 7	40	812.4	258.7
50	594.4	145.0	50	699.9	196.9	50	814.9	260.2
55	596.5	146.0	**63**	702.2	198.0	**71**	817.4	261.6
10	598.7	146.9	10	704.5	199.3	10	819.9	263.1
20	600.8	147 9	20	706.8	200.5	20	822.4	264.6
30	602.9	148.9	30	709.1	201.7	30	825.0	266 1
40	605.0	149.9	40	711.4	202.9	40	827.5	267.5
50	607.2	150.9	50	713.7	204.1	50	830.0	269.0
56	609.3	151.9	**64**	716.1	205.3	**72**	832.6	270.5
10	611.4	152.9	10	718.4	206 6	10	835.1	272.0
20	613.6	153.9	20	720.7	207 8	20	837.7	273.5
30	615.7	154.9	30	723.0	209.0	30	840.2	275.0
40	617.9	156.0	40	725.4	210.3	40	842.8	276.6
50	620.0	157.0	50	727 7	211.5	50	845.4	278.1

TABLE XIV.—Tangents and Externals to a 1° Metric Curve.—Continued.

Angle.	Tang.	Exter.	Angle.	Tang.	Exter.	Angle.	Tang.	Exter.
73°	847.9	279.6	**81°**	978.7	361.1	**89°**	1126.1	460.7
10′	850.5	281.1	10′	981.6	362.9	10′	1129.4	463.0
20	853.1	282.7	20	984.5	364.8	20	1132.7	465.3
30	855.7	284.2	30	987.4	366.7	30	1136.0	467.6
40	858.3	285.8	40	990.3	368.6	40	1139.3	470.0
50	860.9	287.4	50	993.2	370.5	50	1142.6	472.3
74	863.5	288.9	**82**	996.1	372.4	**90**	1145.9	474.7
10	866.1	290.5	10	999.1	374.4	10	1149.3	477.0
20	868.8	292.1	20	1002.0	376.3	20	1152.6	479.4
30	871.4	293.7	30	1005.0	378.2	30	1156.0	481.8
40	874.0	295.3	40	1007.9	380.2	40	1159.3	484.2
50	876.7	296.9	50	1010.9	382.1	50	1162.7	486.6
75	879.3	298.5	**83**	1013.8	384.1	**91**	1166.1	489.0
10	882.0	300.1	10	1016.8	386.1	10	1169.5	491.4
20	884.6	301.7	20	1019.8	388.1	20	1172.9	493.9
30	887.3	303.3	30	1022.8	390.1	30	1176.3	496.3
40	889.9	305.0	40	1025.8	392.0	40	1179.8	498.8
50	892.6	306.6	50	1028.8	394.1	50	1183.2	501.2
76	895.3	308.3	**84**	1031.8	396.1	**92**	1186.6	503.7
10	898.0	309.9	10	1034.8	398.1	10	1190.1	506.2
20	900.7	311.6	20	1037.9	400.1	20	1193.6	508.7
30	903.4	313.3	30	1040.9	402.2	30	1197.1	511.2
40	906.1	314.9	40	1043.9	404.2	40	1200.5	513.7
50	908.8	317.6	50	1047.0	406.3	50	1204.0	516.3
77	911.5	318.3	**85**	1050.1	408.3	**93**	1207.6	518.8
10	914.2	320.0	10	1053.1	410.4	10	1211.1	521.4
20	917.0	321.7	20	1056.2	412.5	20	1214.6	523.9
30	919.7	323.4	30	1059.3	414.6	30	1218.2	526.5
40	922.4	325.1	40	1062.4	416.7	40	1221.7	529.1
50	925.2	326.9	50	1065.5	418.8	50	1125.3	531.7
78	928.0	328.6	**86**	1068.6	420.9	**94**	1228.9	534.3
10	930.7	330.3	10	1071.7	423.1	10	1232.4	536.9
20	933.5	332.1	20	1074.8	425.2	20	1236.0	539.6
30	936.3	333.8	30	1078.0	427.3	30	1239.7	542.2
40	939.0	335.6	40	1081.1	429.5	40	1243.3	544.9
50	941.8	337.4	50	1084.3	431.7	50	1246.9	547.6
79	944.6	339.2	**87**	1087.4	433.8	**95**	1250.6	550.3
10	947.4	340.9	10	1090.6	436.0	10	1254.2	553.0
20	950.2	342.7	20	1093.8	438.2	20	1257.9	555.7
30	953.1	344.5	30	1097.0	440.4	30	1261.6	558.4
40	955.9	346.3	40	1100.2	442.6	40	1265.3	561.1
50	958.7	348.2	50	1103.4	444.9	50	1269.0	563.9
80	961.5	350.0	**88**	1106.6	447.1	**96**	1272.7	566.6
10	964.4	351.8	10	1109.8	449.3	10	1276.4	569.4
20	967.2	353.6	20	1113.1	451.6	20	1280.1	572.2
30	970.1	355.5	30	1116.3	453.9	30	1283.9	575.0
40	973.0	357.3	40	1119.6	456.1	40	1287.7	577.8
50	975.8	359.2	50	1122.8	458.4	50	1291.5	580.6

TABLE XIV.—Tangents and Externals to a 1° Metric Curve.—Concluded.

Angle.	Tang.	Exter.	Angle.	Tang.	Exter.	Angle.	Tang.	Exter.
97°	1295.2	583.5	**105°**	1493.4	736.5	**113°**	1731.3	930.8
10′	1299.0	586.3	10′	1497.9	740.0	10′	1736.8	934.8
20	1302.9	589.2	20	1502.4	743.6	20	1742.3	939.4
30	1306.7	592.1	30	1507.0	747.2	30	1747.8	944.1
40	1310.5	594.9	40	1511.5	750.9	40	1753.4	948.7
50	1314.4	597.8	50	1516.1	754.5	50	1759.0	953.4
98	1318.2	600.8	**106**	1520.7	758.2	**114**	1764.6	958.1
10	1322.1	603.7	10	1525.3	761.9	10	1770.2	962.8
20	1326.0	606.6	20	1529.9	765.6	20	1775.9	967.6
30	1329.9	609.6	30	1534.6	769.3	30	1781.5	972.3
40	1333.8	612.6	40	1539.3	773.0	40	1787.3	977.1
50	1337.8	615.5	50	1543.9	776.8	50	1793.0	982.0
99	1341.7	618.5	**107**	1548.6	780.6	**115**	1798.8	986.8
10	1345.7	621.5	10	1553.4	784.4	10	1804.5	991.7
20	1349.6	624.6	20	1558.1	788.2	20	1810.3	996.6
30	1353.6	627.6	30	1562.9	792.0	30	1816.2	1001.6
40	1357.6	630.7	40	1567.6	795.9	40	1822.1	1006.5
50	1361.6	633.7	50	1572.4	799.7	50	1828.0	1011.5
100	1365.7	636.8	**108**	1577.2	803.6	**116**	1833.9	1016.5
10	1379.7	639.9	10	1582.1	807.6	10	1839.8	1021.6
20	1373.8	643.0	20	1586.9	811.5	20	1845.8	1026.7
30	1377.8	646.2	30	1591.8	815.4	30	1851.8	1031.8
40	1381.9	649.3	40	1596.7	819.4	40	1857.8	1036.9
50	1386.0	652.5	50	1601.6	823.4	50	1863.9	1042.1
101	1390.1	655.6	**109**	1606.5	827.4	**117**	1870.0	1047.2
10	1394.3	658.8	10	1611.5	831.5	10	1876.1	1052.5
20	1398.4	662.0	20	1616.5	835.5	20	1882.3	1057.7
30	1402.5	665.2	30	1621.6	839.6	30	1888.4	1063.0
40	1406.7	668.5	40	1626.5	843.7	40	1894.6	1068.3
50	1410.9	671.7	50	1631.5	847.8	50	1900.9	1073.6
102	1415.1	675.0	**110**	1636.6	851.9	**118**	1907.1	1079.0
10	1419.3	678.2	10	1641.6	856.1	10	1913.4	1084.4
20	1423.6	681.5	20	1646.7	860.3	20	1919.8	1089.8
30	1427.8	684.9	30	1651.9	864.5	30	1926.1	1095.3
40	1432.1	688.2	40	1657.0	868.7	40	1932.5	1100.8
50	1436.3	691.5	50	1662.2	873.0	50	1938.9	1106.3
103	1440.6	694.9	**111**	1667.3	877.2	**119**	1945.4	1111.9
10	1444.9	698.3	10	1672.5	881.5	10	1951.9	1117.5
30	1449.3	701.6	20	1677.8	885.8	20	1958.4	1123.1
30	1453.6	705.0	30	1683.0	890.2	30	1965.0	1128.8
40	1458.0	708.5	40	1688.3	894.5	40	1971.5	1134.5
50	1462.3	711.9	50	1693.6	898.9	50	1978.2	1140.2
104	1466.7	715.4	**112**	1698.9	903.3	**120**	1984.8	1145.9
10	1471.1	718.8	10	1704.3	907.8	10	1991.5	1151.7
20	1475.6	722.3	20	1709.6	912.2	20	1998.2	1157.5
30	1480.0	725.8	30	1715.0	916.7	30	2005.0	1163.4
40	1484.4	729.4	40	1720.4	921.2	40	2011.8	1169.3
50	1488.9	732.9	50	1725.9	925.7	50	2018.6	1175.2

TABLE XV.

Corrections for Externals, Metric Curves, Add.

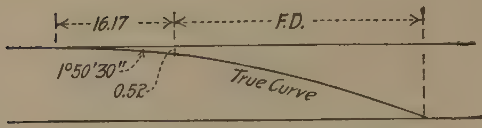
Angle.	3° Curve	5° Curve	7° Curve	9° Curve	11° Curve
20°	.001	.001	.002	.002	.002
30°	.001	.002	.004	.005	.006
40°	.002	.004	.006	.008	.010
50°	.004	.007	.010	.013	.016
60°	.006	.011	.015	.020	.025
70°	.01	.02	.02	.03	.04
80°	.01	.02	.03	.04	.05
90°	.02	.03	.04	.05	.07
100°	.02	.04	.06	.07	.09
110°	.03	.05	.07	.10	.12
120°	.04	.07	.10	.13	.16

Corrections for Tangents, Metric Curves, Add.

Angle.	3° Curve	5° Curve	7° Curve	9° Curve	11° Curve
10°	.00	.01	.01	.01	.01
20°	.01	.01	.02	.02	.03
30°	.01	.02	.03	.03	.04
40°	.01	.03	.04	.05	.06
50°	.02	.03	.05	.06	.07
60°	.02	.04	.06	.08	.09
70°	.03	.05	.07	.09	.11
80°	.03	.06	.08	.11	.13
90°	.04	.07	.10	.13	.16
100°	.05	.09	.12	.15	.19
110°	.06	.10	.14	.19	.23
120°	.07	.12	.17	.23	.28

TABLE XVI.

Table of Frogs and Switches.



Length of switch rail.. 16.17
Throw 0 52
Switch angle .... 1°-50'-30'

No.	Angle.	F. D.	Radius.	Degree
4	14 - 15 - 00	29.64	136 15	43 - 09
4½	12 - 40 - 50	32.89	173.15	33 - 34
5	11 - 25 - 16	36 04	214 92	26 - 54
5½	10 - 23 - 20	39.11	265.73	21 - 41
6	9 - 31 - 38	42.09	313.25	18 - 22
6½	8 - 47 - 50	45.00	370.16	15 - 32
7	8 - 10 - 16	47.83	432.52	13 - 17
7½	7 - 37 - 42	50.59	500.46	11 - 28
8	7 - 09 - 10	53.27	574.32	9 - 59
8½	6 - 43 - 58	55.89	654.43	8 - 46
9	6 - 21 - 34	58.45	740.97	7 - 44
9½	6 - 01 - 32	60.93	834.26	6 - 52
10	5 - 43 - 34	63.32	934.31	6 - 08
10½	5 - 27 - 10	65.73	1,033.35	5 - 33
11	5 - 12 - 18	68.05	1,160.10	4 - 56
11½	4 - 58 - 48	70.30	1,283.55	4 - 28
12	4 - 46 - 18	72.52	1,418.35	4 - 02
12½	4 - 34 - 52	74.68	1,562.15	3 - 40
13	4 - 24 - 20	76.79	1,716.15	3 - 20
13½	4 - 14 - 32	78.85	1,882.35	3 - 03
14	4 - 05 - 28	80.86	2,060 05	2 - 47
14½	3 - 57 - 00	82.83	2,251 65	2 - 33
15	3 - 49 - 06	84.76	2,457 65	2 - 20

STADIA REDUCTION TABLES.

Computed by Mr. Arthur Winslow for use in Pennsylvania Geological Survey Report.

Example of use:

Rod is held perpendicular to a level plane.

Vertical angle, 4° 23'.

Distance read on rod, 543 ft.

From Table XVII., interpolating between 4° 22' and 4° 24':

Correction for hor. dist. 99.415

Diff. of elev. 7.62

Actual hor. distance .... = 5.43 × 99.415 = 539.82

Diff. in elevation .... = 5.43 × 7.62 = 41.38

TABLE XVII.—Stadia Reduction Table.

M.	0° Hor. Dist.	0° Diff. Elev.	1° Hor. Dist.	1° Diff. Elev.	2° Hor. Dist.	2° Diff. Elev.	3° Hor. Dist.	3° Diff. Elev.	4° Hor. Dist.	4° Diff. Elev.	5° Hor. Dist.	5° Diff. Elev.	6° Hor. Dist.	6° Diff. Elev.	7° Hor. Dist.	7° Diff. Elev.	8° Hor. Dist.	8° Diff. Elev.	9° Hor. Dist.	9° Diff. Elev.	10° Hor. Dist.	10° Diff. Elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78	97.55	15.45	96.98	17.10
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15	98.05	13.84	97.53	15.51	96.96	17.16
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21	98.03	13.89	97.52	15.56	96.94	17.21
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26	98.01	13.95	97.50	15.62	96.92	17.26
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32	98.00	14.01	97.48	15.67	96.90	17.32
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38	97.98	14.06	97.46	15.73	96.88	17.37
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43	97.97	14.12	97.44	15.78	96.86	17.43
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49	97.95	14.17	97.43	15.84	96.84	17.48
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55	97.93	14.23	97.41	15.89	96.82	17.54
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60	97.92	14.28	97.39	15.95	96.80	17.59
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66	97.90	14.34	97.37	16.00	96.78	17.65
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72	97.88	14.40	97.35	16.06	96.76	17.70
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77	97.87	14.45	97.33	16.11	96.74	17.76
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83	97.85	14.51	97.31	16.17	96.72	17.81
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	9.04	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88	97.83	14.56	97.29	16.22	96.70	17.86
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	9.09	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94	97.82	14.62	97.28	16.28	96.68	17.92
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00	97.80	14.67	97.26	16.33	96.66	17.97
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05	97.78	14.73	97.24	16.39	96.64	18.03
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11	97.76	14.79	97.22	16.44	96.62	18.08
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17	97.75	14.84	97.20	16.50	96.60	18.14
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22	97.73	14.90	97.18	16.55	96.57	18.19
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28	97.71	14.95	97.16	16.61	96.55	18.24
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33	97.69	15.01	97.14	16.66	96.53	18.30
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39	97.68	15.06	97.12	16.72	96.51	18.35
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45	97.66	15.12	97.10	16.77	96.49	18.41
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50	97.64	15.17	97.08	16.83	96.47	18.46
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56	97.62	15.23	97.06	16.88	96.45	18.51
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61	97.61	15.28	97.04	16.94	96.42	18.57
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67	97.59	15.34	97.02	16.99	96.40	18.62
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73	97.57	15.40	97.00	17.05	96.38	18.68
$c=0.75$	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05	0.75	0.06	0.75	0.07	9.75	0.08	0.74	0.10	0.74	0.11	0.74	0.12	0.74	0.14
$c=1.00$	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13	0.99	0.15	0.99	0.16	0.98	0.18
$c=1.25$	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16	1.23	0.18	1.23	0.21	1.23	0.23

TABLE XVII.—Continued.

M.	11°		12°		13°		14°		15°		16°		17°		18°		19°		20°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	96.36	18.73	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
2	96.34	18.78	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83	88.26	32.18
4	96.32	18.84	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87	88.23	32.23
6	96.29	18.89	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92	88.19	32.27
8	96.27	18.95	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97	88.15	32.32
10	96.25	19.00	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01	88.11	32.36
12	96.23	19.05	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06	88.08	32.41
14	96.21	19.11	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10	88.04	32.45
16	96.18	19.16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15	88.00	32.49
18	96.16	19.21	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19	87.96	32.54
20	96.14	19.27	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24	87.93	32.58
22	96.12	19.32	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28	87.89	32.63
24	96.09	19.38	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33	87.85	32.67
26	96.07	19.43	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38	87.81	32.72
28	96.05	19.48	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42	87.77	32.76
30	96.03	19.54	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47	87.74	32.80
32	96.00	19.59	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51	87.70	32.85
34	95.98	19.64	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56	87.66	32.89
36	95.96	19.70	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60	87.62	32.93
38	95.93	19.75	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65	87.58	32.98
40	95.91	19.80	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69	87.54	33.02
42	95.89	19.86	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74	87.51	33.07
44	95.86	19.91	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78	87.47	33.11
46	95.84	19.96	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83	87.43	33.15
48	95.82	20.02	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87	87.39	33.20
50	95.79	20.07	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92	87.35	33.24
52	95.77	20.12	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96	87.31	33.28
54	95.75	20.18	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01	87.27	33.33
56	95.72	20.23	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05	87.24	33.37
58	95.70	20.28	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09	87.20	33.41
$c=0.75$	0.73	0.15	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25	0.70	0.26
$c=1.00$	0.98	0.20	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27	0.96	0.28	0.95	0.30	0.95	0.32	0.94	0.33	0.94	0.35
$c=1.25$	1.22	0.25	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34	1.20	0.36	1.19	0.38	1.19	0.40	1.18	0.42	1.17	0.44

TABLE XVII.—Concluded.

M.	21° Hor. Dist.	21° Diff. Elev.	22° Hor. Dist.	22° Diff. Elev.	23° Hor. Dist.	23° Diff. Elev.	24° Hor. Dist.	24° Diff. Elev.	25° Hor. Dist.	25° Diff. Elev.	26° Hor. Dist.	26° Diff. Elev.	27° Hor. Dist.	27° Diff. Elev.	28° Hor. Dist.	28° Diff. Elev.	29° Hor. Dist.	29° Diff. Elev.	30° Hor. Dist.	30° Diff. Elev.
0	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45	76.50	42.40	75.00	43.30
2	87.12	33.50	85.93	34.77	84.69	36.01	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49	77.91	41.48	76.45	42.43	74.95	43.33
4	87.08	33.54	85.89	34.82	84.65	36.05	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52	77.86	41.52	76.40	42.46	74.90	43.36
6	87.04	33.59	85.85	34.86	84.61	36.09	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55	77.81	41.55	76.35	42.49	74.85	43.39
8	87.00	33.63	85.80	34.90	84.57	36.13	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59	77.77	41.58	76.30	42.53	74.80	43.42
10	86.96	33.67	85.76	34.94	84.52	36.17	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62	77.72	41.61	76.25	42.56	74.75	43.45
12	86.92	33.72	85.72	34.98	84.48	36.21	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66	77.67	41.65	76.20	42.59	74.70	43.47
14	86.88	33.76	85.68	35.02	84.44	36.25	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69	77.62	41.68	76.15	42.62	74.65	43.50
16	86.84	33.80	85.64	35.07	84.40	36.29	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72	77.57	41.71	76.10	42.65	74.60	43.53
18	86.80	33.84	85.60	35.11	84.35	36.33	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76	77.52	41.74	76.05	42.68	74.55	43.56
20	86.77	33.89	85.56	33.15	84.31	36.37	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79	77.48	41.77	76.00	42.71	74.49	43.59
22	86.73	33.93	85.52	35.19	84.27	36.41	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82	77.42	41.81	75.95	42.74	74.44	43.62
24	86.69	33.97	85.48	35.23	84.23	36.45	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86	77.38	41.84	75.90	42.77	74.39	43.65
26	86.65	34.01	85.44	35.27	84.18	36.49	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89	77.33	41.87	75.85	42.80	74.34	43.67
28	86.61	34.06	85.40	35.31	84.14	36.53	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92	77.28	41.90	75.80	42.83	74.29	43.70
30	86.57	34.10	85.36	35.36	84.10	36.57	82.80	37.74	81.47	38.86	80.09	39.93	79.68	40.96	77.23	41.93	75.75	42.86	74.24	43.73
32	86.53	34.14	85.31	35.40	84.06	36.61	82.76	37.77	81.42	38.89	80.04	39.97	78.63	49.99	77.18	41.97	75.70	42.89	74.19	43.76
34	86.49	34.18	85.27	35.44	84.01	36.65	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02	77.13	42.00	75.65	42.92	74.14	43.79
36	86.45	34.23	85.23	35.48	83.97	36.69	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06	77.09	42.03	75.60	42.95	74.09	43.82
38	86.41	34.27	85.19	35.52	83.93	36.73	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09	77.04	42.06	75.55	42.98	74.04	43.84
40	86.37	34.31	85.15	35.56	83.89	36.77	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12	76.99	42.09	75.50	43.01	73.99	43.87
42	86.33	34.35	85.11	35.60	83.84	36.80	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16	76.94	42.12	75.45	43.04	73.93	43.90
44	86.29	34.40	85.07	35.64	83.80	36.84	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19	76.89	42.15	75.40	43.07	73.88	43.93
46	86.25	34.44	85.02	35.68	83.76	36.88	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22	76.84	42.19	75.35	43.10	73.83	43.95
48	86.21	34.48	84.98	35.72	83.72	36.92	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26	76.79	42.22	75.30	43.13	73.78	43.98
50	86.17	34.52	84.94	35.76	83.67	36.96	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29	76.74	42.25	75.25	43.16	73.73	44.01
52	86.13	34.57	84.90	35.80	83.63	37.00	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32	76.69	42.28	75.20	43.18	73.68	44.04
54	86.09	34.61	84.86	35.85	83.59	37.04	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35	76.64	42.31	75.15	43.21	73.63	44.07
56	86.05	34.65	84.82	35.89	83.54	37.08	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39	76.59	42.34	75.10	43.24	73.58	44.09
58	86.01	34.69	84.77	35.93	83.50	37.12	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42	76.55	42.37	75.05	43.27	73.52	44.12
$c=0.75$	0.70	0.27	0.69	0.29	0.69	0.30	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35	0.66	0.36	0.65	0.37	0.65	0.38
$c=1.00$	0.93	0.37	0.92	0.38	0.92	0.40	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46	0.88	0.48	0.87	0.49	0.86	0.51
$c=1.25$	1.16	0.46	1.15	0.48	1.15	0.50	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58	1.10	0.60	1.09	0.62	1.08	0.64

APPENDIX A

The following article on Methods of Determination of Latitude, Longitude, and Solar Time, by Wm. S. Post, formerly of the U. S. Geological Survey, was published in Engineering News of March 1st, 1900, and will furnish all the information necessary for the locating engineer in the very few times he has occasion to make these determinations.

In reconnaissance work the engineer is frequently required to make use of methods and formulas which are only to be found scattered through separate works on navigation, surveying and astronomy. The purpose of the present compilation is to assemble together certain of these methods, formulas and references; especially such as have been found useful in topographic reconnaissance in Alaska; though these data are applicable anywhere for work of a similar character.

Definitions.

Astronomical.—Heavenly bodies are located by three systems of co-ordinates.

First System of Co-ordinates.—Altitude and Azimuth.—The origin is the place of observation. The primitive circle is the horizon, the horizontal plane tangent to the surface of the earth at the observer. The other axis is through the vertical line, which projected forms the zenith point of the observer. Angles around the horizon are the horizontal angles of surveying, and when the plane through the meridian line is taken as the plane of reference, they become the azimuths of astronomy. In astronomy and triangulation the south point is taken as zero, and angles of azimuth are measured from left around to right 360°. In surveying each quadrant is usually specified as S. W., N. W., etc. Angles in the vertical plane are the vertical angles of surveying, or the altitudes of astronomy measured in each case from the horizon or level line.

Second System of Co-ordinates.—Declination and Hour Angle.—The origin is the center of the earth. The primitive circle is the terrestrial equator, and at right angles to it are meridian circles through the axis of the earth. The reference circle is the meridian plane through the place of observation; and hour angles are angles on either side of the meridian, as they would be obtained at the center of the earth. Declination is any angle at the earth's center measured in a meridian plane north and south from the equator, as zero.

Third System of Co-ordinates.—Declination and Right Ascension.—Differs from the second only in substituting for the plane through the local meridian a constant reference plane through a constellation.

The last two of these systems refer to the same point as origin, or the center of the earth. Since all the stars are practically at an infinite distance, it is assumed for purposes of computation that the "place of the observer" in the first system is identical with the center of the earth. The distance of the sun is so great that, for working purposes, this same assumption is true also in its case; but it is not true for the moon and planets, where the difference is not negligible; and observations on them must first be reduced to the earth's center. As the three systems may be said to have origin and planes in common, the data of one can be transformed into those of the others, formulas for which are given in works on astronomy.

Terrestrial latitude and longitude fall under the second and third systems of co-ordinates. The latitude of a place is the angle at the earth's center between the equator and the place of observation; that is, it is identical with the declination of the zenith of the place. Longitude measures in hour angles the angle at the earth's center between a reference circle (usually the meridian of Greenwich) and the meridian of the place of observation.

NOTATION.

h = altitude.
z = 90° — altitude = zenith distance.
A = azimuth.
d = declination.
P = 90° — declination = Polar distance.
R.A. = right ascension.
L = latitude.
M = longitude.
t = hour angle

Latitude.

Latitude is required in nearly every computation which follows, and naturally falls first in order of computation, although frequently not in the order of observation. It is best observed by taking the highest altitude of the sun at noon, or of stars as they successively pass the meridian; or, on Polaris at any time; or, by observing the sun or a star on the prime vertical. Roughly, one mile of northing or southing equals one minute of latitude, and latitude can often be supplied, when not observed, from former determinations and other data of survey. The angle required is an "altitude," that is, a vertical angle from horizon or level up to the celestial object. Hence a sextant, a transit or any instrument carrying a vertical arc will do. The accuracy depends upon the least count of the arc and the sensitiveness of the level. An instrument reading to minutes may be expected to give latitude within one mile, etc.

I. Latitude by observation of the sun at noon. An altitude is taken to the upper or lower edge (called "limb") of the sun at its highest altitude; in practice this is done by commencing a few minutes before noon and observing successive angles until the sun transits and begins to descend. The highest angle is then taken for latitude computation. To deduce the latitude, the sun's declination at the time of observation must be first determined from the Nautical Almanac, or any solar Ephemeris published by the various instrument firms.

(a) To determine declination, take out from the tables

Declination at Greenwich, apparent noon for date......	..° ..′ ..″
Add algebraically $\left\{\dfrac{\text{longitude west from Greenwich}}{15}\right\}$ multiplied by diff. for 1 hr.	..′ ..″
Declination at local apparent noon =	..° ..′ ..″

North declination is considered +, and south —; west longitude is considered +, and east —. The sign of "difference for 1 hour" is given in the tables.

(b) To determine the latitude:

Altitude angle observed	..° ..′ ..″
Subtract refraction, Table I.	..′ ..″
True altitude sun's $\left\{\begin{matrix}\text{upper}\\ \text{lower}\end{matrix}\right\}$ limb....................	..° ..′ ..″

Subtract Semi-diam., for {upper / lower} limb observed / Add	..°	..′	..″
True altitude, sun's center	..°	..′	..″
Subtract algebraically declination (a) ±	..°	..′	..″
Co-latitude	..°	..′	..″
Subtract co-latitude from 90°........................	90°	..′	..″
Latitude*	..°	..′	..″

The longitude used in calculating declination (a) need not be accurately known. It is sufficient to roughly estimate from maps. Semi-diameter may be taken as 16′ when seconds of arc are not observed. For more accurate work the Nautical Almanac gives the semi-diameter for each day. For solar observations an assistant may hold a piece of smoked or colored glass in front of the eye-piece or objective; or better, a screen of colored glass is attached to the eye-piece, arranged so as to be turned out of the field when not required.

Example 1. Latitude.—On August 20, 1898, in approximate longitude 162° W., the altitude of the sun's lower limb at noon was found to be 41° 23′.

(a) Declination Gr. app. noon, Aug. 20, +	12°	21′	59″
Add $\frac{162^\circ}{15} \times (-50'')$ .... —		09′	..″
Declination local app. noon, Aug. 20, +	12°	12′	59″
(b) Altitude angle observed	41°	23′	..″
Subtract refraction, Table I.		01′	..″
True altitude sun's lower limb	41°	22′	..″
Add semi-diameter sun		16′	..″
Altitude sun's center	41°	38′	..″
Subtract declination (a) .... +	12°	13′	..″
Co-latitude	29°	25′	..″
Subtract co-latitude from 90°....................	90°	..′	..″
Latitude	60°	35′	..″

Example 2. Latitude.—On March 4, 1898, in approximate long. 95 W., the sun's upper limb was observed at noon by sextant to be 45° 58′ 20″.

*"The American Ephemeris and Nautical Almanac" is published for each year by the Bureau of Equipment, Navy Department, Washington, D. C. W. & L. E. Gurley, Troy, N. Y., and Riggs & Bro., 221 Walnut St., Philadelphia, Pa., publish abridgments of the "Nautical Almanac," useful in field work.

(a) Declination Gr. app. noon, Mar. 4 .... —	6°	15′	31″
Add $\frac{95^{\circ}}{15} \times (+58'')$ .... +		6′	07″
Declination, local app. noon, Mar. 4, —	6°	09′	24″
(b) Altitude angles observed	45°	58′	20″
Subtract refraction, Table I.		0′	56″
True altitude sun's upper limb	45°	57′	24″
Subtract semi-diameter sun		16′	09″
Altitude sun's center	45°	41′	15″
Subtract declination (a) .... —	6°	09′	24″
Co-latitude	51°	50′	39″
Subtract co-latitude from 90°	90°	00′	00″
Latitude	38°	09′	21″

II. Latitude by any star at its highest altitude or meridian passage.—A meridian can be obtained roughly by the needle or turning on the north star. Note any constellation, which may be near the meridian, and select a star from the star list. Observe the star until it reaches its highest altitude. The formula is the same as for the sun, but simpler, because a star has a constant declination and no diameter.

Computation for South Altitudes.

Altitude angle observed	..°	..′	..″
Subtract refraction		..′	..″
True altitude star	..°	..′	..″
Subtract algebraically declination	..°	..′	..″
Co-latitude	..°	..′	..″
Subtract co-latitude from 90°	90°	00′	00″
Latitude	..°	..′	..″

Computation for North Altitudes.

Altitude angle observed	..°	..′	..″
Subtract refraction		..′	..″
True altitude	..°	..′	..″
Add declination	..°	..′	..″
Latitude + 90°	..°	..′	..″
Subtract 90°	90°	00′	00″
Latitude	..°	..′	..″

Example 3. Latitude.—At a certain place on a certain night, the following meridian altitudes were observed: Vega (α Lyrae) S. 66° 41′, Altair (α Aquilae) S. 36° 36′, and Polaris (upper culmination) N. 63° 17′.

	Vega.			Altair.		
Altitude observed	S. 66°	41′	00″	S. 36°	36′	00″
Subtract refraction		0′	25″		1′	19″
True altitude	66°	40′	35″	36°	34′	41″
Subtract declination	38°	41′	19″	8°	35′	56″
Co-latitude	27°	59′	16″	27°	58′	45″
Subtract from 90°	90°	00′	00″	90°	00′	00″
Latitude	62°	00′	44″	62°	1′	15″

	Polaris.		
Altitude observed	N. 63°	17′	00″
Subtract refraction		0′	29″
True altitude	63°	16′	31″
Add declination	88°	45′	09″
Latitude + 90°	152°	1′	40″
Subtract 90°	90°	00′	00″
	62°	01′	40″

III. Latitude by observations of the North Star at any time, local time being known.—This method is given in the American Ephemeris and Nautical Almanac accompanied by the necessary tables for the reduction for each year.

IV. By observations of the sun or star on the prime vertical.—Chauvenet, in a note on this method, says: "Since the star's declination is not required, this method has the additional advantage (which may at times be of great importance to the traveler), of being practicable without the use of the Ephemeris. This feature entitles this method to a prominent place in works of navigation." He gives it as follows:

We have

$$\frac{dz}{15\,dt} = \cos L, \sin A.$$

If, then, we observe two altitudes near the prime vertical in quick succession, noting the times by a stop-watch with as great precision as possible, and denote the difference of the altitudes, or of the zenith distances by d z, and the difference of the times by d t, we shall have

$$\cos L = \frac{dz}{15\,dt} \operatorname{cosec} A.$$

The observation being made near the prime vertical, an error in the supposed azimuth A will have but small influence upon the

result. If the observation is exactly in the prime vertical, or within a few minutes of it, we may put

$$\cos L = \frac{dz}{15\,dt}.$$

This exceedingly simple method, though not susceptible of great precision, may be very useful to the navigator, as it is available when the sun is exactly east or west, and, consequently, when no other method is practicable, and, moreover, requires no previous knowledge of the time or the approximate latitude, or of the star's declination.

Example 4.—1853, July 3, Prestel observed near the prime vertical the time required by the sun to change its altitude by a quantity equal to its apparent diameter. By observing with a sextant: first, the contact of the lower limb with its image in an artificial horizon, and then the contact of the upper limb with its image, the sextant reading being the same at both observations, namely, 30° 15′ 0″, he found

	Chronometer.
Contact of lower limb........................	4 h. 43 mins. 34.0 secs. p. m.
Contact of upper limb........................	4 h. 47 mins. 5.5 secs. p. m.
	3 mins. 31.5 secs.

The sun's diameter was 31′ 32″. Hence we have

d z = 31 mins. 32 secs. = 1,892 secs.	log............	3.2769
d t = 3 " 31.5 " = 211.5 "	ar. co. log.....	7.6747
	log 1/15	8.8239
L = 53° 23.5′	Log. cos. L....	9.7755

The azimuth, however, was not exactly 90°, but about 88° 20′.

Hence we shall have, more exactly		9.7755
A = 88° 20′...........	log. cosec. A	0.0002
L = 53° 22.3′........	log. cos. L	9.7757

It is evident that the method will be more precise in high latitudes than in low ones.

Latitude by Altitudes near the Meridian.—If, for instance, the noon observation of the sun has been prevented by clouds, an observation taken later may be reduced to meridian as follows; time from local apparent noon, that is, the hour angle being noted; if local time is not known, the azimuth of the reading must be taken:

(a) To reduce an azimuth A to corresponding hour angle t, the observed altitude corrected for refraction being h.

$$\tan M = \text{co-tan } h . \cos A.$$
$$\tan t = \frac{\tan A . \sin M.}{\cos (L - M)}.$$

L being taken approximately.

(b) Latitude.

$$\tan D = \tan d. \times \sec t.$$
$$\cos Y = \sin h, \sin D \ \text{cosec } d.$$
$$L = D \pm Y.$$

Azimuth or Meridian Line. (See also Appendix B.)

Azimuth may be obtained by observing Polaris at elongation, latitude being known; or by any star (including Polaris and the sun) at any time, latitude being known. The General Land Office publishes in its "Manual of Surveying Instructions," an excellent method and table for Polaris azimuths for any time, local time and latitude being known.

I. Polaris at Elongation.—At the instant of elongation we have

$$\sin A = \frac{\cos d.}{\cos L}.$$

The elongation may be determined by following the star with a transit until it reaches its fullest motion east or west, and accepting the greatest angle observed. Whether the elongation is east or west may be noted from the course of the star. Trautwine gives the diagram (Fig. 72) by which it can be determined in the field, from the fact that at elongation the star Alioth, of the constellation Great Bear, is nearly on a horizontal line with Polaris.

II. By any Star (including Polaris and the Sun), Latitude alone being known.—The further the star is from meridian, the more accurate the method becomes; except it must not be so low on the horizon as to have excessive refraction. The sun, for instance, is best observed between 8 and 10 o'clock in the morning, and between 2 and 4 o'clock in the afternoon.

(a) Method of Observing the Sun.—Two observations are made. The horizontal plate of the transit is clamped in a position where the sun is just entering the field. When the first limb contacts the vertical cross hair, the horizontal cross hair is contacted

with the upper limb, and the vertical angle recorded. When the second limb contacts, the horizontal cross hair is brought to the lower limb, and vertical angle recorded. By diagram this may be shown as follows:

Morning. Afternoon.

The horizontal angle reading will be the position of the sun's center corresponding to the mean of the two vertical angle readings. Some terrestrial object should be observed as an azimuth mark. If local time is also required the watch time of the successive contacts should also be carefully noted, and the mean taken. It must be noted roughly for computing declination. The record is then (for an afternoon observation):

	Angles		Time		
	Horizontal.	Vertical.			
Sun's I. and lower limb......	..° ..′	..° ..′	..h.	..m.	..s.
Sun's II. and upper limb....	..° ..′	..° ..′	..h.	..m.	..s.
Sun's center (mean)		..° ..′	..h.	..m.	..s.
Correction for refraction....		..′			
Sun's center	..° ..′	..° ..′	..h.	..m.	..s.
Azimuth mark	..° ..′				

The formulas are

$$s = \tfrac{1}{2}\,(P + L + h);$$

$$\tan^2 \tfrac{1}{2} A = \frac{\sin\,(s - L)\ \sin\,(s - h)}{\cos s.\ \cos\,(s - P)}.$$

To find polar distance we require declination at time of observation, computation being the same as before given.

Declination at Greenwich, apparent noon for date of observation	..° ..′ ..″
Add	
$\left\{\dfrac{\text{Long. w. fr. Gr.}}{15} \pm \begin{matrix}\text{hrs., \&c.,}\\ \text{after or}\\ \text{bef. noon}\end{matrix}\right\} \times \text{diff. for 1 hr.}$	..′ ..″
Declination time of observation	..° ..′ ..″
Subtract declination from 90°	90° 00′ 00″
Polar distance = P	..° ..′ ..″

For logarithmic computation we have

P	..° ..′ ..″	
L	..° ..′ ..″	
h	..° ..′ ..″	
Sum 2	..° ..′ ..″	
S	..° ..′ ..″	sec................
s — h	..° ..′ ..″	sin................
s — L	..° ..′ ..″	sin................
s — P	..° ..′ ..″	sec................
Check sum	..° ..′ ..″	2) ————
	log. tan ½ A =	————
	½ A =	..° ..′ ..″

Angle from true north to position at observation = A = ..° ..′ ..″

Bowditch's "Useful Tables," Bureau of Equipment, Navy Department, Washington, D. C., gives log, secants and cosecants, as well as log, sines and cosines, and is very convenient in this computation. If a table of secants is not available, it is only necessary to remember that log. secant = 10 — log. cosine. The "check sum" fails when s is smaller than h, L or P; but the computation remains the same, taking simply the difference of the quantities in each case.

Example 5, Solar Azimuth.—In Alaska, Lat. 62° 00′ 30″, Long. 151° 51′, July 5, 1898, the instrument set up with 0° 0′ of plate at the south end of needle. (A preliminary variation of 26° 10′ was used on the variation plate, that observed at a preceding station.) A sharp peak was observed as an azimuth mark, and the following observations were made on the sun for azimuth:

Point.	Angle: Horizontal.	Angle: Vertical.	Time
True south*	359° 56′ 00″		
Needle south†	0° 00′ 00″		
Azimuth mark	79° 07′ 00″		
Sun:			July 5.
(A) I. and lower limb......	300° 39′ 00″	39° 40′	21h. 09m. 45s.
II. and upper limb......		40° 30′	21h. 12m. 40s.
			July 5.
(B) I. and upper limb......	314° 30′ 30″	44° 45′	21h. 58m. 15s.
II. and lower limb......		44° 24′	22h. 00m. 47s.
			July 6.
(C) I and lower limb......	49° 02′ 00″	43° 20′	2h. 37m. 26s.
II. and upper limb......		43° 38′	2h. 39m. 56s.

*Determined below. †Var. 26° 10′.

	Azi. A.		Azi. B.		Azi. C.	
Greenwich declination, July 6.......	+22° 40′ 36″		+22° 40′ 36″		+22° 40′ 30″	
Add corr. (longitude and time)......	— 1′ 49″*		— 2′ 01″†		— 3′ 10″‡	
Declination, time of observation..	22° 38′ 47″		22° 38′ 35″		22° 37′ 26″	
	90° 00′ 00″		90° 00′ 00″		90° 00′ 00″	
P = ...	67° 21′		67° 21.5′		67° 22.5′	
L = ...	62° 00.5′		62° 00.5′		62° 00.5′	
h (corrected for refraction)..........	40° 04′		44° 33.5′		43° 28′	
Sum = 2 s	169° 25.5′		173° 55.5′		172° 51′	
S sec.	84° 42.7′	11.03542	86° 57.7′	11.27571	86° 25.5′	11.20513
s — h sin.	44° 38.7′	9.84677	42° 24.2′	9.82888	42° 57.5′	9.83330
s — L sin.	22° 42.2′	9.58656	24° 57.2′	9.62520	24° 25′	9.61674
s — P sec.	17° 21.7′	10.02025	19° 36.2′	10.02593	19° 03′	10.02446
	169° 25.3′	2|20.48900	173° 55.3′	2|20.75572	172° 51.0′	2|20.67923
Log. tan ½ A = ...		10.24450		10.37786		10.33961
½ A = ...	60° 20′ 20″		67° 1[illegible]′		65° [illegible]	
∴ = ...	120° 41′ 00″		134° 32		130° 50	
Azi. from south	300° 41′ 00″		314° 32′ 00″		49° 10′	
Horizontal angle reading	300° 39′ 00″		314° 30′ 30″		49° 02′	
Plate reading of true south.......	359° 58′ 00″		359° 58′ 30″		359° 52′	

Average reading of true south....359° 56′.

Resulting variation........................26° 14′.

*(+ 10.1h. — 2.8h.) x — 15″.
†(+ 10.1h — 2h.) x — 15″.
‡(10.1h + 2.6h.) x — 15″.

(b) The method is simplified for stars. The horizontal position of the observation being noted and a vertical angle taken, we first find the star's Polar Distance.

$$P = 90^\circ - d.$$

	°	′	″
Declination from star tables	..	..	..
Subtract from 90°	90	00	00
Polar distance	..	..	..

The computation is the same as in Example 5. Planets may be used, but have a constantly changing Declination, and have to be reduced in a manner similar to the Sun.

FIG. 72.

III. Azimuth by Polaris, at any Time, Local Time and Latitude being known.—The Manual of Surveying Instructions, General Land Office, Washington, D. C., gives (pp. 109-119) complete data for observing the North Star for meridian, as practiced in Land Survey. (Appendix B.)

Time.

Watch or Clock Correction.—If,

T = the watch time.
T' = the true time.
dT = the clock correction,

then,

$$T' = T + dT.$$

or,

$$dT = T' - T.$$

The watch correction will be + or —, according as the watch is slow or fast.

Rate of Watch.—The rate of the watch is determined by observing time on successive days at the same place. By dividing the difference of the watch corrections observed by the number

of days between the observations, we get the rate per day, either increase of fastness, or slowness or decrease of fastness or slowness, which are indicated by the signs of the correction and of the rate. By formula, if we designate two observed times by T and T_0 the rate of r T is

$$r\,T = \frac{d\,T - d\,T_0}{T - T_0},$$

and the true time T″ at any future date corresponding to a watch time T

$$T'' = T + d\,T_0 + r\,T\,(T - T_0).$$

Time Definitions.—Apparent local noon is the time of transit or meridian passage of the sun, at a given place. Apparent time is measured from Apparent noon. Mean local noon is the time of transit of a theoretical mean sun. The Mean day is the time between successive transits of the mean sun. The Civil day divides this day into an a. m. and p. m. period of twelve hours each, while the Astronomical day divides it into 24 hours, commencing at noon of the same Civil date. They are easily convertible; for example:

Astronomical time.		Civil time.
Feb. 11, 2 hrs.	=	Feb. 11, 2 p. m.
Feb. 11, 15 "	=	Feb. 12, 3 a. m.
May 31, 22 "	=	June 1, 10 a. m.

Astronomical time is used entirely in time computations, and it is convenient to record all time observations at once in this 24-hour time. The Equation of Time is the varying difference in time between Apparent and Mean time, and is given in the Solar Ephemeris. The Local Sidereal day is the interval between the successive transits of a point in the constellation Aries. It commences at this transit, and is divided into 24 hours. The sidereal time of transit of any star after the transit of Aries is its Right Ascension. The Civil and Astronomical day is 3m. 56s. longer than the sidereal day. Tables for their conversion into each other are given in the Nautical Almanac, Tables II. and III. Stars are catalogued by their Right Ascensions and Declination.

To Determine Local Mean Time. I. By transit of sun at noon. —An accurate meridian being established and instrument aligned upon it, the successive transits of the sun's first and second limb are noted by the watch.

Transit sun's I. limb..............................	..h.	..m.	..s
Transit sun's II. limb..............................	..h.	..m.	..s.
2)	..h.	..m.	..s.
Transit of center..............................	..h.	..m.	..s.
= watch time of apparent local noon.			
Subtract algebraically equation of time .... ±		..m.	..s.
Watch time of local mean noon	..°	..′	..″
Watch, fast or slow on mean time	..°	..′	..″

Equation of time is given on Page I. of the Nautical Almanac for Greenwich, Apparent noon. A small correction must be made for Longitude (reduced to hours), by multiplying hours in W. Long. by "diff. for 1 hour," in last column. Adding to Greenwich equation of time we have local equation of time for date. Regard carefully sign of equation of time as given in precept at the head of the column. The equation of time is to be subtracted algebraically, that is, subtracted when precept is plus; added when minus.

II. By Equal Altitudes of the Sun Before and After Noon.—Sextant or transit. Does not require a meridian. This requires Tables in "Bowditch's Useful Tables," No. 37, or Chauvenet's "Practical Astronomy," Vol. II., No. iv.

T = time of apparent noon.
$D\,d$ = Increase of declination in 1 hr. (Page 1 "Nautical Almanac.")
h = sun's true altitude.
T_0 = mean watch time of two observations.
$D\,T_0$ = correction to this mean.
t = elapsed time.
A = tabular value for elapsed time.
B = tabular value for elapsed time.

Then

$$a = A.\ D\,d \tan L.$$
$$b = B.\ D\,d \tan d.$$
$$D\,T_0 = a + b$$
$$T = T_0 + D\,T_0.$$

the equation of time subtracted from T will give watch time of local mean noon. The signs of quantities a and b must be carefully attended to. A and B are both given in the table; the sign of D d is in the ephemeris. L is + when north Latitude, and d + when north declination.

III. By Time Sight on Sun, at any Time, Latitude being known.—The vertical angles on Sun's upper and lower limb are taken, and the exact time of each observation. Then we have by taking the mean of each,

(a) Observed altitude of sun's center.................. ..° ..′ ..″
Subtract refraction ....

True altitude sun's center ....° ..′ ..″
occurring at date, ..h. ..m. ..s. (mean of observations).
(b) The formulæ are:

$$s = \tfrac{1}{2}(P + L + h),$$

$$\tan^2 \tfrac{1}{2} t = \frac{\cos s. \sin (s - h)}{\sin (s - L) \cos (s - P)}$$

t = hour-angle expressed in degrees, minutes and seconds.
(c) Observed time (mean of observation)........ ..h. ..m. ..s.

Add, if before noon.......... $\dfrac{\text{Hour-angle}}{15}$ ..h. ..m. ..s.
Subtract, if after noon.......

Watch time of local apparent noon............ ..h. ..m. ..s.
Subtract algebraically eq. of time...... ± ..m. ..s.

Watch time of local mean noon ....h. ..m. ..s.

Formula (b) requires the same quantities as the Solar Azimuth. The observations will be complete for either purpose if horizontal angle, vertical angles to upper and lower limbs, and corresponding times of contact be taken. To illustrate, take the observations for azimuth in Example 5, where the times are noted. P, L, h and s are the same.

TABLE XVIII. MEAN REFRACTION.

Barometer, 30 ins. Fahrenheit's Thermometer, 50°.

Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″
				6	0	8	28.0	7	30	6	57.1	9	0	5	52.6	10	30	5	4.6
0	0	36	29.4		5	8	22.1		35	6	53.0		5	5	49.6		35	5	2.3
1	0	24	53.6		10	8	16.2		40	6	48.9		10	5	46.6		40	5	0.0
2	0	18	25.5		15	8	10.5		45	6	44.9		15	5	43.6		45	4	57.8
3	0	14	25.1		20	8	4.8		50	6	41.0		20	5	40.7		50	4	55.6
4	0	11	44.4		25	7	59.3		55	6	37.1		25	5	37.9		55	4	53.4
5	0	9	52.0	6	30	7	53.9	8	0	6	33.3	9	30	5	35.1	11	0	4	51.2
	5	9	44.0		35	7	48.7		5	6	29.6		35	5	32.4		5	4	49.1
	10	9	36.2		40	7	43.5		10	6	25.9		40	5	29.6		10	4	47.0
	15	9	28.6		45	7	38.4		15	6	22.3		45	5	27.0		15	4	44.9
	20	9	21.2		50	7	33.5		20	6	18.8		50	5	24.3		20	4	42.9
	25	9	14.0		55	7	28.6		25	6	15.3		55	5	21.7		25	4	40.9
5	30	9	7.0	7	0	7	23.8	8	30	6	11.9	10	0	5	19.2	11	30	4	38.9
	35	9	0.1		5	7	19.2		35	6	8.5		5	5	16.7		35	4	36.9
	40	8	53.4		10	7	14.6		40	6	5.2		10	5	14.2		40	4	35.0
	45	8	46.8		15	7	10.1		45	6	2.0		15	5	11.7		45	4	33.1
	50	8	40.4		20	7	5.7		50	5	58.8		20	5	9.3		50	4	31.2
	55	8	34.2		25	7	1.4		55	5	55.7		25	5	6.9				

TABLE XVIII. MEAN REFRACTION.—Concluded.

Barometer, 30 ins. Fahrenheit's Thermometer, 50°.

Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″	Apparent altitude. °	′	Mean refraction. ′	″
	55	4	29.4		50	3	10.3	24	0	2	10.2	34	0	1	26.2	48	0	0	52.5
12	0	4	27.5	17	0	3	8.3		10	2	9.2		20	1	25.1	49	0	0	50.6
	5	4	25.7		10	3	6.4		20	2	8.2		40	1	24.1	50	0	0	48.9
	10	4	23.9		20	3	4.6		30	2	7.2	35	0	1	23.1	51	0	0	47.2
	15	4	22.2		30	3	2.8		40	2	6.2		20	1	22.0	52	0	0	45.5
	20	4	20.4		40	3	1.0		50	2	5.3		40	1	21.0	53	0	0	43.9
	25	4	18.7		50	2	59.2	25	0	2	4.4	36	0	1	20.1	54	0	0	42.3
12	30	4	17.0	18	0	2	57.5		10	2	3.4		20	1	19.1	55	0	0	40.8
	35	4	15.3		10	2	55.8		20	2	2.5		40	1	18.2	56	0	0	39.3
	40	4	13.6		20	2	54.1		30	2	1.5	37	0	1	17.2	57	0	0	37.8
	45	4	12.0		30	2	52.4		40	2	0.7		20	1	16.3	58	0	0	36.4
	50	4	10.4		40	2	50.8		50	1	59.8		40	1	15.4	59	0	0	35.0
	55	4	8.8		50	2	49.2	26	0	1	58.9	38	0	1	14.5	60	0	0	33.6
13	0	4	7.2	19	0	2	47.7		10	1	58.1		20	1	13.6	61	0	0	32.3
	5	4	5.6		10	2	46.1		20	1	57.2		40	1	12.7	62	0	0	31.0
	10	4	4.1		20	2	44.6		30	1	56.4	39	0	1	11.9	63	0	0	29.7
	15	4	2.6		30	2	43.1		40	1	55.5		20	1	11.0	64	0	0	28.4
	20	4	1.0		40	2	41.6		50	1	54.7		40	1	10.2	65	0	0	27.2
	25	3	59.6		50	2	40.2	27	0	1	53.9	40	0	1	9.4	66	0	0	25.9
13	30	3	58.1	20	0	2	38.8		10	1	53.1		20	1	8.6	67	0	0	24.7
	35	3	56.6		10	2	37.4		20	1	52.3		40	1	7.8	68	0	0	23.6
	40	3	55.2		20	2	36.0		30	1	51.5	41	0	1	7.0	69	0	0	22.4
	45	3	53.7		30	2	34.6		40	1	50.7		20	1	6.2	70	0	0	21.2
	50	3	52.3		40	2	33.3		50	1	50.0		40	1	5.4	71	0	0	20.1
	55	3	50.9		50	2	32.0	28	0	1	49.2	42	0	1	4.7	72	0	0	18.9
14	0	3	49.5	21	0	2	30.7		20	1	47.7		20	1	3.9	73	0	0	17.8
	10	3	46.8		10	2	29.4		40	1	46.2		40	1	3.2	74	0	0	16.7
	20	3	44.2		20	2	28.1	29	0	1	44.8	43	0	1	2.4	75	0	0	15.6
	30	3	41.6		30	2	26.9		20	1	43.4		20	1	1.7	76	0	0	14.5
	40	3	39.0		40	2	25.7		40	1	42.0		40	1	1.0	77	0	0	13.5
	50	3	36.5		50	2	24.5	30	0	1	40.6	44	0	1	0.3	78	0	0	12.4
15	0	3	34.1	22	0	2	23.3		20	1	39.3		20	0	59.6	79	0	0	11.3
	10	3	31.7		10	2	22.1		40	1	38.0		40	0	58.9	80	0	0	10.3
	20	3	29.4		20	2	20.9	31	0	1	36.7	45	0	0	58.2	81	0	0	9.2
	30	3	27.1		30	2	19.8		20	1	35.5		20	0	57.6	82	0	0	8.2
	40	3	24.8		40	2	18.7		40	1	34.2		40	0	56.9	83	0	0	7.2
	50	3	22.6		50	2	17.5	32	0	1	33.0	46	0	0	56.2	84	0	0	6.1
16	0	3	20.5	23	0	2	16.4		20	1	31.8		20	0	55.6	85	0	0	5.1
	10	3	18.4		10	2	15.4		40	1	30.7		40	0	55.0	86	0	0	4.1
	20	3	16.3		20	2	14.3	33	0	1	29.5	47	0	0	54.3	89	0	0	1.0
	30	3	14.2		30	2	13.3		20	1	28.4		20	0	53.7	87	0	0	3.1
	40	3	12.2		40	2	12.2		40	1	27.3		40	0	53.1	88	0	0	2.0
					50	2	11.2									90	0	0	0.0

Note on Table of Mean Refraction.—This table is given for average conditions, a barometer of 30 inches and thermometer of 50°, and is sufficiently accurate without correction for rough observations. For more precise computations, tables for reduction to barometer and thermometer are given in Chauvenet's "Spherical and Practical Astronomy" Vol. II., Table XIV.; and Bowditch, "American Practical Navigation," Tables 21 and 22.

EXAMPLE 6. (Data from Example 5.)

(b)

	A.		B.		C.	
S cos	84 42.7	8.96458	86 57.7	8.72438	86 25.5	8.79487
s — h sin.........	44 38.7	9.84677	42 24.2	9.82888	42 57.5	9.83330
s — L cosec......	22 42.2	10.41346	24 57.2	10.37481	24 25.0	10.38366
s — P sec........	17 21.7	10.02025	19 36.2	10.02593	19 03.0	10.02446
		19.24506		18.95400		19.03629
Log. tan ½ t =		9.62253		9.47700		9.51814

	A.	B.	C.
½ t =	22° 45′	16° 41′ 40″	18° 15′
t =	45° 30′	33° 23′ 20″	36° 30′
	3h. 02m.	2h. 13m. 33s.	2h. 26m

(c)

	A.		B.		C.	
	July		July		July	
Observed time	5,	21:11:12	5,	21:59:31	6,	2:38:41
Hour angle		3:02:00		2:13:33		2:26:00
Watch time of apparent noon	6,	0:13:12	6,	0:13:04	6,	0:12:41

Mean of observation apparent noon, July 6........	oh.	12m.	59s.
Equation of time (local) subtract	oh.	04m.	33s.
Watch time of local mean noon................		08m.	26s.

Watch fast ....Correction = d T =	—	8m.	26s.
Equation of time, Greenwich, July 6......................	=	4m.	29s.
Longitude 10.1h. × .43 (difference of 1 hour)............	=	om.	4s.
Local equation time	=	4m.	33s.

IV. By Transit of Star.—The instant of meridian passage of a star being noted by the watch, local mean time may be computed. For certainty in identification of star, its altitude should be carefully observed (which may be also used for Latitude determination). We have observed, then,

Watch time of star's transit; date.................. (Expressed in 24 hours' time.)	..h.	..m.	..s.
Also altitude.......... ..° ..′ ..″.			
From Ephemeris, P. II., column sidereal time, or R. A. of mean sun, for date.................	..h.	..m.	..s
Correction for hours of longitude west from Greenwich, Table III.,* add		..m.	..s.
Local R. A., mean sun for date............	..h.	..m.	..s.
From star table, R. A., star observed...............	..h.	..m.	..s.
Difference = elapsed sidereal time	..h.	..m.	..s.
Cor. Table II.* for elapsed time, subtract		..m.	..s.
Elapsed solar time	..h.	..m.	..s.
Add or subtract from obs. watch time star's transit.	..h.	..m.	..s.
Watch time of local mean noon	..h.	..m.	..s.

*Tables II. and III. of "Nautical Almanac" are meant.

Longitude.

Longitude is best determined by telegraph exchange of time. In field practice a good chronometer or watch alone can be used.

I. The difference in local mean time is the difference in Longitude. $M = (T_0 - T)$, in which T_0 and T are local mean times at two meridians T and T_0. If the longitude of either is known the other can be determined by observing "watch time of noon" at one point, carrying the watch to the other and again observing for local noon. The difference in watch time is the longitude expressed in time, that is, in hours, minutes and seconds. Multiply by 15 to get corresponding degrees, minutes and seconds. The rate of the watch must be known, and the correction applied.

II. By Sextant Lunar Distances.—The method is especially adapted for sextant, and is used at sea to check chronometers or recover Greenwich time in case of accident to chronometers. This, like the method III., does not require any knowledge of the longitude. It determines it absolutely, not relatively, as in method I., from the fact of the rapid motion of the moon with reference to other heavenly bodies. The computation of Lunar Distances is given in full in Bowditch's "Practical Navigator," pp. 133-141, accompanied by the necessary tables. The computation is somewhat tedious, and method III. will be found easier if a transit is to be had.

III. Longitude by Transits of Moon and a Star or the Sun. Latitude being known.—An accurate meridian being established, the transit of the moon's bright limb is observed. Either before or after, a transit of the sun or a star must be observed. The observed transit is reduced to transit of moon's center by adding or subtracting semi-diameter, expressed in time, p. IV. Nautical Almanac, according as the I. or II. limb is observed. The sun's transit is reduced to center by averaging the readings for I. and II. limbs, and correcting by equation of time, to watch time of mean local noon. By subtracting one from the other we get the difference in time (mean time units) between the sun and the moon, or "elapsed time."

From p. II. of the Nautical Almanac we have the Sidereal Time, or R. A. of Mean Sun at Greenwich. Making the proper correction for longitude (assuming a rough longitude) we get

the local R. A. of Mean Sun. Adding or subtracting elapsed time (corrected to sidereal units) we have R. A. of Moon, which we denote a_1. Referring now to the hourly Ephemeris of the Moon given in the Nautical Almanac, we have:

T_1 = mean Greenwich time required corresponding to a_1	..h. ..m. ..s.
..h. ..m. ..s. = T_0 = Greenwich hour of table immediately preceding and corresponding to R. A. a_0 = ...	..h. ..m. ..s.
$a_1 - a_0$ = ...	..s.

D a = increase in R. A. in 1 minute of mean time T_0.
d a = increase of D a in 1 hour.

To find T_1 (Chauvenet's "Practical Astronomy")

$$x' = \frac{60\ (a_1 - a_0)}{L\ a};\ x'' = \frac{x'^2}{7{,}200} \cdot \frac{d\ a}{D\ a};$$

(x'' will be positive when D a is decreasing and negative when D a is increasing).

$$x = x' + x''.$$
$$T_1 = T_0 + x.$$

T_1, which is the Greenwich time of the moon observation expressed in mean time units, is now converted into the corresponding Greenwich sidereal time $= H_1$. The difference between H_1 and a_1 is Longitude from Greenwich = M; M = $H_1 - a_1$.

Example 7.—In Latitude 59° 48′, roughly, 10.5 hours west longitude from Greenwich, the following observations were made September 11, 1898, a watch with inappreciable rate being used:

Transit of moon's II. limb at Sept. 10.............	21h. 05m. 28s.
Mean of transits sun's I. and II. limbs, Sept. 11....	0h. 12m. 29s.
Computation.	
Transit sun's center........................Sept. 11.	0h. 12m. 29s.
Local equation of time	3m. 39s.
Watch time, mean local noon.........Sept 11.	0h. 16m. 08s.
Transit moon's II. limb...................Sept. 10.	21h. 05m. 28s.
Semi-diameter 14′ 53″, subtract....................	59s.
Watch time, transit moon's center.............	21h. 04m. 29s.
Elapsed time (mean time units).....................	3h. 11m. 39s.
Corr. Table III. "Nautical Almanac"...............	32s.
Elapsed sidereal time	3h. 12m. 11s.
R. A. sun Greenwich ....Sept. 11.	11h. 22m. 07s.
Corr. Table III. for Long. 10.5h.	1m. 43s.
Local R. A. sun ....Sept. 11.	11h. 23m. 50s.

Subtract elapsed sidereal time......................	3h.	12m.	11s.
R. A. moon = a_1 ....Sept. 11.	8h.	11m.	39s.
..h. ..m. ..s. = T_1 = required mean Greenwich time, corresponding to a_1 = ... Sept. 11.	8h.	11m.	39s.
Sept. 11. 7h. 00m. 00s. = T_0 = preceding Gr. hour from Ephemeris, corresponding to a tabular R. A. = a_0 = ...Sept. 11.	8h.	10m.	43s.
$a_1 - a_0$ = ...			56s.

From Ephemeris D a = 2.0154s.
From Ephemeris d a = .0025s.

$$x' = \frac{60 \times 56}{2.0154} = 1{,}667.2\text{s.}$$

$$x'' = \frac{(1{,}667.2)^2}{7{,}200} \cdot \frac{.0025}{2.0154} = +\ 0.5\text{s.}$$

$$x = x' + x'' = 1{,}668\text{s.}$$

$T_1 = T_1 + x.$

T_1 = Sept. 11......................................	7h.	24m.	28s
Greenwich R. A. mean sun....................Sept. 11.	11h.	22m.	07s.
Corr. Table III. for 7h. 24m..........................		1m.	13s.
H_1 = ...Sept. 11.	18h.	47m.	48s.
a_1 = ...Sept. 11.	18h.	11m.	39s.
M = ...	10h.	36m.	09s.

IV. If we have the Latitude and Longitude of a point P and an Azimuth on a second point P′, and at P′ observe the Latitude, we can compute the approximate Longitude of P′ by the following formula:

$$M' = M + \frac{u \cdot \sin A}{\cos L'};$$

For P′ north of P:

$$\sin u = \frac{\sin (L' - L)}{\cos A};$$

For P′ south of P:

$$\tan u = \frac{\tan (L - L')}{\cos A}.$$

u is expressed in seconds of arc; L, M and A are Latitude, Longitude and Azimuth at P, L′, M′ are Latitude and Longitude at P′.

APPENDIX B.

The notes and tables necessary for the determination of the True Meridian by observations of Polaris are taken from the U. S. Magnetic Declination Tables for 1902, p. 79, published by the Coast and Geodetic Survey:

To Determine the True Meridian by Observation on Polaris at Elongation with a Surveyor's Transit.

1. Set a stone, or drive a wooden plug, firmly in the ground, and upon the top thereof make a small distinct mark.

2. About thirty minutes before the time of the eastern or western elongation of Polaris, as given by the tables of elongation, No. XIX., set up the transit firmly, with its vertical axis exactly over the mark, and carefully level the instrument.

3. Illuminate the cross hairs by the light from a bull's-eye lantern or other source, the rays being directed into the object end of the telescope by an assistant. Great care should be taken to see that the line of collimation describes a truly vertical plane.

4. Place the vertical hair upon the star, which, if it has not reached its elongation, will move to the right for eastern and to the left for western elongation.

5. As the star moves toward elongation, keep it continually covered by the vertical hair by means of the tangent screw of the vernier plate, until a point is reached where it will appear to remain on the hair for some time and then leave it in a direction contrary to its former motion, thus indicating the point of elongation.

6. At the instant the star appears to thread the vertical hair, depress the telescope to a horizontal position; about 100 yards north of the place of observation drive a wooden plug, upon which by a strongly illuminated pencil or other slender object, exactly coincident with the vertical hair, mark a point in the line of sight thus determined; then *quickly* revolve the vernier plate 180°, again place the vertical hair upon the star, and, as before, mark a point in the new direction; then the middle point between the two marks, with the point under the instrument, will define on the ground the trace of the vertical plane through Polaris at its eastern or western elongation, as the case may be.

7. By daylight lay off to the east or west, as the case may require, the proper azimuth taken from Table No. XX.; the instrument will then define the *true meridian*, which may be per-

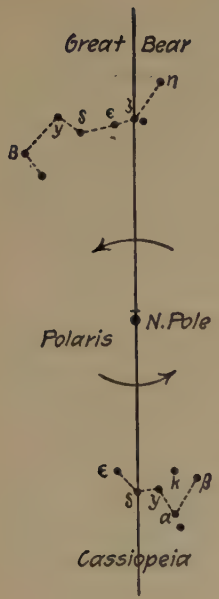


FIG. 73.

manently marked by monuments for future reference.

Figure 73 held perpendicular to the line of sight directed to the pole, with the right-hand side of the page uppermost, will represent the configuration of the constellations with Polaris near *eastern* elongation at midnight about July 11. *Inverted,* it will show Zeta (ς) of the Great Bear and Polaris on the meridian (the former *below* and the latter *above* the pole) at midnight about October 10; and held with left-hand side uppermost, the diagram will indicate the relative situations for midnight about January 8, with Polaris near *western* elongation. The arrows indicate the direction of apparent motion.

TABLE XIX.

Local mean (astronomical) time of the culminations and elongations of Polaris in the year 1902.

Computed for latitude 40° north and longitude 90° or 6^h west of Greenwich.

Date. 1902.	East. elongation. h. m.	Upper culmination. h. m.	West. elongation. h. m.	Lower culmination. h. m.
January 1	0 46.2	6 41.2	12 36.2	18 39.3
January 15	23 47.1	5 45.9	11 40.9	17 44.0
February 1	22 40.0	4 38.8	10 33.8	16 36.9
February 15	21 44.7	3 43.5	9 38.5	15 41.6
March 1	20 49.5	2 48.3	8 43.3	14 46.4
March 15	19 54.3	1 53.1	7 48.1	13 51.2
April 1	18 47.4	0 46.2	6 41.2	12 44.3
April 15	17 52.2	23 47.2	5 46.0	11 49.1
May 1	16 49.4	22 44.4	4 43.2	10 40.3
May 15	15 54.5	21 49.5	3 48.3	9 51.4
June 1	14 47.9	20 42.9	2 41.7	8 44.8
June 15	13 53.0	19 48.0	1 46.8	7 49.9
July 1	12 50.4	18 45.4	0 44.2	6 47.3
July 15	11 55.6	17 50.6	23 45.6	5 52.5
August 1	10 49.1	16 44.1	22 39.1	4 40.0
August 15	9 54.2	15 49.2	21 44.2	3 51.1
September 1	8 47.6	14 42.6	20 37.6	2 44.5
September 15	7 52.7	13 47.7	19 42.7	1 49.0
October 1	6 49.9	12 44.9	18 39.9	0 46.8
October 15	5 54.9	11 49.9	17 44.9	23 48.0
November 1	4 48.1	10 43.1	16 38.1	22 41.2
November 15	3 53.0	9 48.0	15 43.0	21 46.1
December 1	2 49.9	8 44.9	14 39.9	20 43.0
December 15	1 54.7	7 49.7	13 44.7	19 47.8

A. *To refer the above tabular quantities to years subsequent to 1902:*

For year 1903	add	1.4 minutes		
1904	add	2.8	"	up to March 1
	subtract	1.1	"	on and after March 1
1905	add	0.2	"	
1906	"	1.5	"	
1907	"	2.9	"	
1908	"	4.2	"	up to March 1
		0.3	"	on and after March 1
1909	"	1.7	"	
1910	"	3.0	"	

B. *To refer to any calendar day other than the first and fifteenth of each month,* SUBTRACT *the quantities below from the tabular quantity for the* PRECEDING DATE.

Day of month.		Minutes.	No. of days elapsed.
2 or	16	3.9	1
3	17	7.9	2
4	18	11.8	3
5	19	15.8	4
6	20	19.7	5
7	21	23.6	6
8	22	27.6	7
9	23	31.5	8
10	24	35.5	9
11	25	39.4	10
12	26	43.3	11
13	27	47.3	12
14	28	51.2	13
	29	55.2	14
	30	59.1	15
	31	63.0	16

C. *To refer the table to Standard time and to the civil or common method of reckoning:*

([a]) ADD to the tabular quantities four minutes for every degree of longitude the place is west of the Standard meridian and SUBTRACT when the place is east of the Standard meridian.

([b]) The astronomical day begins twelve hours after the civil day, i. e., begins at noon on the civil day of the same date, and is reckoned from 0 to 24 hours. Consequently an astronomical time less than twelve hours refers to the same civil day, whereas an astronomical time greater than twelve hours refers to the morning of the next civil day.

It will be noticed that for the tabular year two eastern elongations occur on January 12 and two western elongations on July 12. There are also two upper culminations on April 12 and two lower culminations on October 12. The lower culmination either follows or precedes the upper culmination by $11^h\ 58^m.1$.

D. *To refer to any other than the tabular latitude between the limits of 25° and 50° North:* ADD to the time of west. elongation $0^m.13$ for every degree south of 40° and SUBTRACT from the time of west. elongation $0^m.18$ for every degree north of 40°. Reverse these operations for correcting times of east. elongation.

E. *To refer to any other than the tabular longitude*: ADD $0^m.16$ for each 15° east of the ninetieth meridian and SUBTRACT $0^m.16$ for each 15° west of the ninetieth meridian.

TABLE XX.

Azimuth of Polaris when at elongation for any year between 1902 *and* 1910.

Latitude.	1902.	1903.	1904.	1905.	1906.	1907.	1908.	1909.	1910.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
25°	1 20.5	1 20.1	1 19.8	1 19.4	1 19.1	1 18.7	1 18.4	1 18.1	1 17.7
26	21.1	20.8	20.5	20.1	19.8	19.4	19.1	18.7	18.4
27	21.9	21.5	21.2	20.8	20.5	20.1	19.8	19.4	19.1
28	22.6	22.2	21.9	21.6	21.3	20.9	20.5	20.1	19.8
29	23.4	23.0	22.7	22.4	22.1	21.7	21.3	20.9	20.5
30	24.2	23.9	23.5	23.1	22.8	22.4	22.1	21.7	21.3
31	25.1	24.7	24.4	24.0	23.6	23.2	22.9	22.5	22.2
32	26.0	25.6	25.3	24.9	24.5	24.1	23.8	23.4	23.1
33	27.0	26.6	26.2	25.9	25.5	25.1	24.7	24.3	24.0
34	28.0	27.6	27.2	26.9	26.5	26.1	25.7	25.3	25.0
35	29.0	28.7	28.3	27.9	27.5	27.1	26.8	26.4	26.0
36	30.1	29.8	29.4	29.0	28.6	28.2	27.9	27.5	27.1
37	31.3	30.9	30.5	30.1	29.7	29.3	29.0	28.6	28.2
38	32.6	32.2	31.8	31.4	31.0	30.6	30.2	29.8	29.4
39	33.9	33.5	33.1	32.7	32.3	31.8	31.4	31.0	30.6
40	35.2	34.8	34.4	34.0	33.6	33.2	32.8	32.4	32.0
41	36.7	36.2	35.8	35.4	35.0	34.6	34.2	33.8	33.4
42	38.2	37.7	37.3	36.9	36.5	36.0	35.6	35.2	34.8
43	39.8	39.3	38.9	38.5	38.1	37.6	37.2	36.8	36.3
44	41.4	41.0	40.5	40.1	39.7	39.2	38.8	38.4	37.9
45	43.2	42.7	42.3	41.8	41.4	40.9	40.5	40.1	39.6
46	45.0	44.6	44.2	43.7	43.2	42.7	42.3	41.9	41.4
47	46.9	46.5	46.0	45.6	45.1	44.6	44.2	43.7	43.3
48	49.0	48.6	48.1	47.7	47.2	46.7	46.3	45.8	45.3
49	51.2	50.7	50.2	49.8	49.3	48.8	48.4	47.9	47.4
50	1 53.5	1 53.0	1 52.5	1 52.0	1 51.5	1 51.0	1 50.6	1 50.1	1 49.6

The above table was computed with mean declination of Polaris for each year. A more accurate result will be had by applying to the tabular values the following correction, which depends on the difference of the mean and the apparent place of the star. The deduced azimuth will in general be correct within 0′.3.

For middle of	Correction.	For middle of	Correction.
	′		′
January	—0.4	July	+0.3
February	—0.3	August	+0.1
March	—0.2	September	—0.1
April	0.0	October	—0.3
May	+0.2	November	—0.6
June	+0.3	December	—0.8

APPENDIX C.

The following article, which appeared in Engineering News of June 13, 1901, gives in a condensed form all the information required by the locating engineer in laying out spiral curves where such are needed, or allowing for the necessary offsets where the spirals are not actually run in:

Spiral Curves.

By E. Holbrook.*

About 21 years ago the writer found occasion to use transition curves on railroads, and found that the problem had not been worked out. This problem was to make a transition from circle to tangent such that the superlevation of the outer rail should at all points be proportionate to the centrifugal force. This could best be accomplished by passing from circle to tangent by a curve with a uniform rate of transition; the superelevation of the outer rail would then begin at the point of spiral and increase uniformly, reaching the maximum at the point of circle and remaining constant till the decreasing spiral was reached at the other end of the circle. This would give the simplest method for the trackman's use.

The nature of such a spiral is expressed by the equation

$$R\ L = A,$$

when R is the radius of curvature of the spiral at any point; L the length of the spiral measured from its origin, and A a constant which determines the rate of transition.

Having worked out the properties of such a spiral in connection with its relation to the adjacent tangent and circle and put it into use, the writer distributed among various assistant engineers of the "Pan Handle road." copies of the demonstration and tables, and from them it went to other roads. It was published briefly in "The Railroad Gazette" in December, 1880. The first engineer besides the writer to use these formulas extensively was Geo. W. Kittridge, now Chief Engineer of the "Big Four," who put spiral ends on many of the curves of the "Pan Handle," both east and west of Steubenville, O.

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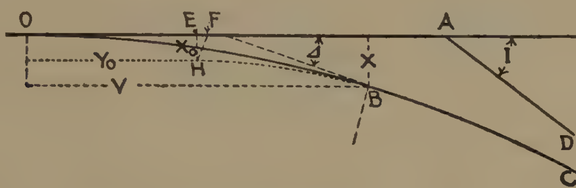
*Chief Engineer, Kansas City Southern Ry. Co., Kansas City, Mo.

Since that time volumes have been written on the subject and many tables arranged, with countless variations, to suit the ideas of engineers as to how best to lay out this curve. They are all, however, but different aspects or parts of what was contained in the original work, and have been made with one or more of three objects in view, viz.: to devise a scheme where tables could be dispensed with; to overcome a fancied want of elasticity, or to escape a little higher mathematics which enter into the demonstration but not into the application.

By the help of the following figure and table the actual work in the field is briefly explained:



Let O A and A D be two tangents, intersecting at the point A, making the angle I.

O B is the spiral connecting the circle H B C with the tangent O A, having a length O B equal L.

Δ is the total curvature of the spiral.

d is the deflection angle to be turned off from the tangent to locate any point, as B.

To locate the point O for any given degree of curve and intersection angle I, we have: $OA = T = AF + FE + EO = R \text{ tang } \frac{1}{2} I + X_0 \text{ tang } \frac{1}{2} I + Y_0$ or $(R + X_0) \text{ tang } \frac{1}{2} I + Y_0$.

If we wish to lay out the spiral with a rate of transition of one degree in 60 ft., enter the Table XXI at the line beginning with the required degree and take out the value of R, to which add by inspection the value of X_0 found on the same line and multiply the sum by tang ½ I, as in ordinary circular curves; to this product add the value of Y_0 found on the same line, and you will have the length of tangent for locating O. Set the transit at O and turn off from the tangent the deflections found in the table for various lengths of spiral for locating the spiral until the required degree is reached, as shown by the figures in the first column. Then set up at B, backsighting on

O, and turn off twice the total deflection of the spiral, and the line of sight will then be on the common tangent of spiral and circle. The circle can then be produced in the usual manner.

Putting in true transition curves adds practically nothing to the work except as they make the curves longer. They can be put in as quickly by one who is familiar with them as any approximate method that is not rank fudging. There are no offsets to make, no parallel tangents, no curve to run that is not used and no stake to drive that is not a center stake, and stakes may be driven at any station and as few or as many as desired.

As to the elasticity of this method, 20 years' experience has demonstrated that a single rate of transition should be used on new work, and it is very rare that more than two are required on old work. If we use two rates, viz.: one degree in thirty ft. and one degree in sixty ft., we can relocate curves up to 6° without getting the stakes outside of the rails; but if some other rate is desired, say one degree in twenty ft., inspect the table. Table No. XXI has a rate of one degree in sixty ft., and No. XXII has one degree in thirty ft. Compare the value of d on corresponding lines of the two tables and note that one is just double the other, or vary as the rate of transition, so we can lay out the desired spiral by adding 50% to the values of d found in Table No. XXII. Note that the values of X_0, on lines beginning with the same degree, are as 4 to 1, or vary inversely as the squares of the rates of transition, which enables us to find the required value of X_0 with very little work. Observe that Y_0 may be obtained by subtracting a small quantity from ½ of L; and observe that this quantity varies in the tables as the cubes of the rates of transition, which enables us to find Y_0 in case the spiral is so long that it cannot be seen by inspection.

Many have objected to the use of the true transition curve because its demonstration requires some higher mathematics. The objection is no better founded than an objection to a table of sines and cosines, because they require the same. A wide experience has demonstrated that young engineers with only a rudimentary knowledge of trigonometry can grasp the general idea and learn to apply it as easily as they can learn to solve a triangle.

At the time that the original demonstration was made the writer did not attempt to ascertain the relation directly between

△ and d, and did not observe for a time that to the limit of the table, $d = \dfrac{\triangle}{3}$ and consequently that the angle at B turned off to get on the common tangent was twice d, that is △ — d = 2d. This ratio does not hold for large values of △, which goes on increasing indefinitely, while d never reaches 65°.

No case has yet occurred to the writer where he could not stake out the whole spiral at one setting; but if the case arises the transit can be moved along the tangent and the remaining deflection easily calculated by use of the values of X and Y found in the tables. Usually, a table like the one given below supplies all that is required; △ being obtained if required by multiplying d by 3.

(1° = 60 ft.)

Degs.	L.	X.	Y.	Y_0	d.
0° 20′	20	0.01	20.00	10.00	0° 00.7′
0° 40′	40	0.03	40.00	20.00	0° 02.7′
1° 00′	60	0.10	60.00	30.00	0° 06.0′
1° 20′	80	0.25	80.00	40.00	0° 10.7′
1° 40′	100	0.48	100.00	50.00	0° 16.7′
1° 50′	110	0.64	110.00	55.00	0° 20.2′
2° 00′	120	0.84	120.00	60.00	0° 24.0′
2° 10′	130	1.06	129.99	65.00	0° 28.2′
2° 20′	140	1.33	139.99	70.00	0° 32.7′
2° 30′	150	1.64	149.98	75.00	0° 37.5′
2° 40′	160	1.99	159.98	80.00	0° 42.7′
2° 50′	170	2.38	169.97	85.00	0° 48.2′
3° 00′	180	2.83	179.96	90.00	0° 54.0′
3° 10′	190	3.33	189.95	95.00	1° 00.1′
3° 20′	200	3.89	199.93	99.99	1° 06.7′
3° 30′	210	4.49	209.91	104.99	1° 13.5′
3° 40′	220	5.16	219.89	109.98	1° 20.7′
3° 50′	230	5.90	229.86	114.98	1° 28.2′
4° 00′	240	6.70	239.83	119.97	1° 36.0′
4° 10′	250	7.58	249.79	124.97	1° 44.2′

If it is desired to use a subchord, or a degree of curvature between those given in the tables, d for the subchord can easily be found by remembering that d increases as the square of the length, X_0 and Y_0 change so slowly that the former may be obtained by second differences and the latter from first differences, as found in the table. For curves of small total curvature it is sometimes best to make the whole curve a transition. In such case the total curvature of each spiral will be △ = ½ I, and the length of the tangent will be y + x tang ½ I. If the rate of transition in the table does not give an external distance to suit

the location, find the ratio of the one given in the table to the one desired and increase or decrease the length of the tangents and the chords used in staking out accordingly, since all such curves between tangents of a given intersection angle are similar.

For the external distance E we have

$$E = x \sec \tfrac{1}{2} I.$$

It is sometimes necessary to put in a circular curve with transition that will have a given external distance, I being given. Find the degree of a simple curve having the required external distance, then

Let

E' = the required external distance,

D = the degree of a simple curve with external E,

D' = the degree of curve with transition and external E',

$$D' = D \left\{ \frac{E + X_0 \sec \frac{1}{2} I}{E} \right\},$$

where X_0 corresponds to D'; but X_0 changes so slowly and the difference between D' and D is not usually over 10 minutes, so the value of X_0 can be estimated sufficiently close to get the value of D' at the first approximation.

If it is desired to find E for any given value of R and I we have

$$E = R \text{ tang } \tfrac{1}{4} I \text{ tang } \tfrac{1}{2} I + X_0 \sec \tfrac{1}{2} I.$$

A large number of special cases of compound and reverse curves with transitions will be found worked out in the appendix to the Ohio State Railway Commission's report for 1884. However, keeping in mind that in all cases the circle is removed a distance X_0 from the tangent, and in compound curves the two circles stand in the same relation to each other that the tangent and circles do in the ordinary case, no difficulty will be experienced.

TABLE XXI.—(1° = 60 ft.)
(Spiral increasing 0° 01′ per ft.)

Degrees.	Radius ft.	L.	△	X.	Y.	X_o.	Y_o.	d.
0° 20′	17188.75	20	0° 02′	0.01	20.00	0.00	10.00	0° 00.7′
0° 40′	8,594.37	40	0° 08′	0.03	40.00	0.01	20.00	0° 02.7′
1° 00′	5,729.60	60	0° 18′	0.10	60.00	0.03	30.00	0° 06.0′
1° 20′	4,297.15	80	0° 32′	0.25	80.00	0.07	40.00	0° 10.7′
1° 40′	3,437.75	100	0° 50′	0.48	100.00	0.11	50.00	0° 16.7′
1° 50′	3,125.21	110	1° 00½′	0.64	110.00	0.16	55.00	0° 20.2′
2° 00′	2,864.80	120	1° 12′	0.84	120.00	0.21	60.00	0° 24.0′
2° 10′	2,644.41	130	1° 24½′	1.06	129.99	0.27	65.00	0° 28.2′
2° 20′	2,455.52	140	1° 38′	1.33	139.99	0.32	70.00	0° 32.7′
2° 30′	2,291.82	150	1° 52½′	1.64	149.98	0.42	75.00	0° 37.5′
2° 40′	2,148.57	160	2° 08′	1.99	159.98	0.52	80.00	0° 42.7′
2° 50′	2,022.20	170	2° 24½′	2.38	169.97	0.60	85.00	0° 48.2′
3° 00′	1,909.85	180	2° 42′	2.83	179.96	0.71	90.00	0° 54.0′
3° 10′	1,809.20	190	3° 00½′	3.33	189.95	0.84	95.00	1° 00.1′
3° 20′	1,718.80	200	3° 20′	3.89	199.93	0.99	99.99	1° 06.7′
3° 30′	1,637.01	210	3° 40½′	4.49	209.91	1.13	104.99	1° 13.5′
3° 40′	1,562.60	220	4° 02′	5.16	219.89	1.28	109.98	1° 20.7′
3° 50′	1,494.66	230	4° 24½′	5.90	229.86	1.48	114.98	1° 28.2′
4° 00′	1,432.39	240	4° 48′	6.70	239.83	1.67	119.97	1° 36.0′
4° 10′	1,375.09	250	5° 12½′	7.58	249.79	1.90	124.97	1° 44.2′
4° 20′	1,322.20	260	5° 38′	8.51	259.75	2.13	129.97	1° 52.7′
4° 30′	1,273.20	270	6° 04½′	9.53	269.70	2.38	134.97	2° 01.5′
4° 40′	1,227.76	280	6° 32′	10.63	279.64	2.66	139.96	2° 10.7′
4° 50′	1,185.40	290	7° 00½′	11.81	289.57	2.96	144.94	2° 20.1′
5° 00′	1,145.91	300	7° 30′	13.07	299.49	3.26	149.92	2° 30.0′
5° 10′	1,108.95	310	8° 00½′	14.42	309.40	3.61	154.91	2° 40.2′
5° 20′	1,074.28	320	8° 32′	15.86	319.29	3.97	159.89	2° 50.7′
5° 30′	1,041.73	330	9° 04½′	17.39	329.17	4.34	164.87	3° 01.5′
5° 40′	1,011.09	340	9° 38′	19.02	339.04	4.76	169.85	3° 12.7′
5° 50′	982.21	350	10° 12½′	20.74	348.89	5.19	174.82	3° 24.2′
6° 00′	954.93	360	10° 48′	22.56	358.72	5.65	179.79	3° 36.0′

TABLE XXII.—(1° = 30 ft.)
(Spiral increasing 0° 02′ per ft.)

Degrees.	Radius ft.	L.	△	X.	Y.	X_o.	Y_o.	d.
0° 20′	17188.75	10	0° 01′	0.00	10.00	0.00	5.00	0° 00.3′
0° 40′	8,594.37	20	0° 04′	0.01	20.00	0.00	10.00	0° 01.3′
1° 00′	5,729.60	30	0° 09′	0.03	30.00	0.01	15.00	0° 03.0′
1° 20′	4,297.15	40	0° 16′	0.06	40.00	0.02	20.00	0° 05.3′
1° 40′	3,437.75	50	0° 25′	0.12	50.00	0.03	25.00	0° 08.3′
2° 00′	2,864.80	60	0° 36′	0.21	60.00	0.05	30.00	0° 12.0′
2° 20′	2,455.53	70	0° 49′	0.33	70.00	0.08	35.00	0° 16.3′
2° 40′	2,148.59	80	1° 04′	0.49	80.00	0.13	40.00	0° 21.3′
3° 00′	1,909.86	90	1° 21′	0.70	90.00	0.17	45.00	0° 27.0′
3° 20′	1,718.89	100	1° 40′	0.97	99.99	0.24	50.00	0° 33.3′
3° 40′	1,562.61	110	2° 01′	1.29	109.99	0.31	55.00	0° 40.3′
4° 00′	1,432.39	120	2° 24′	1.67	119.98	0.41	60.00	0° 48.0′
4° 20′	1,322.21	130	2° 49′	2.12	129.97	0.52	65.00	0° 56.3′
4° 40′	1,227.76	140	3° 16′	2.65	139.95	0.68	70.00	1° 05.3′
5° 00′	1,145.91	150	3° 45′	3.26	149.94	0.81	74.99	1° 15.0′
5° 20′	1,074.29	160	4° 16′	3.96	159.91	0.98	79.98	1° 25.3′
5° 40′	1,011.10	170	4° 49′	4.75	169.88	1.18	84.98	1° 36.3′
6° 00′	954.93	180	5° 24′	5.64	179.84	1.40	89.97	1° 48.0′
6° 20′	904.67	190	6° 01′	6.63	189.79	1.65	94.97	2° 00.3′
6° 40′	859.44	200	6° 40′	7.74	199.73	1.93	99.96	2° 13.3′
7° 00′	818.52	210	7° 21′	8.95	209.66	2.23	104.94	2° 27.0′
7° 20′	781.30	220	8° 04′	10.30	219.57	2.57	109.93	2° 41.3′
7° 40′	747.33	230	8° 49′	11.76	229.46	2.93	114.92	2° 56.3′
8° 00′	716 20	240	9° 36′	13.37	239.33	3.34	119.89	3° 12.0′

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